June 1993

FLOW AUGMENTATION AND RESERVOIR DRAWDOWN: STRATEGIES FOR RECOVERY OF THREATENED AND ENDANGERED STOCKS OF SALMON IN THE SNAKE RIVER

BASIN, Recovery Issues for Threatened and Endangered Snake River Salmon Technical Report 2 of 11,

Technical Report 1993

DOE/BP-99654-2

This report was funded by the Bonneville Power Administration (BPA), U.S. Department of Energy, as part of BPA's program to protect, mitigate, and enhance fish and wildlife affected by the development and operation of hydroelectric facilities on the Columbia River and its tributaries. The views of this report are the author's and do r necessarily represent the views of BPA.

This document should be cited as follows:

Giorgil,Albert E.; S.P. Cramer & Associates, Inc., U.S. Department of Energy, Bonneville Power Administration, Division of Fish and Wildlife, Project No. 93-013, Contract No. DE-AM79-93BP99654, 60 electronic pages (BPA Report DOE/BP-99654-2)

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FLOW AUGMENTATION AND RESERVOIR DRAWDOWN: STRATEGIES FOR RECOVERY OF THREATENED AND ENDANGERED STOCKS OF SALMON IN THE SNAKE RIVER BASIN

Recovery Issues for Threatened and Endangered Snake River Salmon
Technical Report 2 of 11

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U.S. Department of Energy
Bonneville Power Administration
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P.O. Box 3621
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Project No. 93-013
Contract No. DE-AM79-93BP99654

June 1993

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Executive Summary

Within the mainstem impounded Snake River there is convincing evidence that once yearling chinook initiate migration, their migration speed is influenced by flow, or water velocity, over the range of water conditions observed since 1973. The rate of decrease in migration speed increases sharply when flows are below approximately 80 to 90 kcfs. Above that flow migration rate increases little, Similar travel time data are not available for sockeye, but they are presumed to respond similarly.

The effect of speed -of migration on smolt survival has been inferred from a complement of system survival and travel time estimates acquired during the 1970s. Since both the speed of migration and the proportion of fish shunted through various passage routes varied with the flow levels, the system survival estimates reflect the combined effects of reservoir and dam passage. Reservoir mortality estimates have been indirectly derived from the system survival estimates and are presumed to reflect effects associated with speed. No such survival estimates exist for subyearling fall chinook.

The accuracy, precision and relevance of these historical estimates of survival are questionable, so much so that efforts to reproduce them were abandoned in the early 1980s. Smolt survival through the same reaches would undoubtedly differ today, since both passage conditions and the population composition (hatchery/wild) has dramatically changed. Bypasses have been installed or upgraded, spill and flow augmentation programs have been implemented and the proportion of hatchery fish has increased.

Reservoir mortality/flow relationships derived from these historical estimates are the premises for providing increased water velocity and are the foundation for most regional passage models (except CRiSP.l). Basic assumptions regarding the integrity and applicability of these relationships require empirical evaluation.

Some have postulated that a temporally well-defined “biological window” exists for optimum survival of salmonid smolts, at seawater entry. It has been further suggested that migrational delay lessens the probability that smolts will enter that window. However, there is no evidence that seawater adaptation is impaired due to migrational delay for either chinook or sockeye salmon. In fact, the literature indicates chinook are quite plastic in this regard.

Some parties have elected to dismiss the need for quantifying survival benefits associated with migration speed. They contend the primary objective is to maximize migration speed by increasing water velocity. However, water storage is currently too limited in the Snake River Basin to appreciably augment flows during the 2-3 month spring migration period. Preliminary results from System Operation Review indicate that the maximum amount of water available above base flows in any water year, that could be sustained continually during spring migration, would amount to about 7,500 to 10,000 cfs. In low water years, the expected change in yearling chinook travel time over base flow conditions is minimal, e.g., increasing from 40 to 50 kcfs does not equate to much gain in net system travel time. In high water years, the base flows are so high that the additional augmentation is inconsequential in terms of increasing smolt speed, and could be damaging due to gas saturation effects.

To further increase water velocity, particularly during low flow-years, several alternatives have been proposed, including but not limited to; constructing additional storage reservoirs, improving transportation capabilities for smolts, drawing down reservoirs, and pulsing flows.

To what extent will implementation of any of these strategies improve survival above current levels? To answer this we need some measure of what system survival is today. As noted earlier, it should differ from historical levels due to system changes implemented since 1980. There is a fundamental need to acquire reliable estimates of reach, turbine, spillway and bypass survivals to establish that baseline.

Changes in smolt survival associated with reservoir drawdown alternatives are uncertain. The net survival of smolts is the composite of three processes; survival through passage routes and facilities at dams, reservoir survival associated with migration speed, and changes in environmental and ecological conditions. The balance among these will determine the extent to which system survival either increases or decreases as a result of reservoir drawdown. Model analyses predict that increased migration speed is likely even though smaller reservoirs remain, but unpredictable changes in the other two mechanisms can yield either positive or negative net effects, depending on assumptions regarding these mechanisms. A host of empirical studies will have to be conducted before such a strategy is implemented.

Inferences regarding migration speed and the associated changes in smolt survival are based on measures taken from the population-at-large, a mixture of hatchery and wild fish. Migratory dynamics of, and the effects of passage on wild stocks are thought to differ from those of hatchery origin, but few useful measures are available. In the context of ESA, it is advisable that future evaluations strive to provide information on wild stocks'.

Estimates of smolt survival through key reaches of river provide the only meaningful performance measure to quantify the effects of flow augmentation. Efforts to acquire such reach survival estimates should proceed expeditiously. The survival study proposed by NMFS and the University of Washington scientists assesses the feasibility of acquiring reliable survival estimates. I recommend this research be conducted in 1993, as well as studies that assess the effects of migration delay on seawater adaption.

Any drawdown experiment will require estimates of smolt survival through drawndown reservoirs and reconfigured dams, and a study of broad-based ecological effects. The design of these evaluations must be comprehensive and sound, since the risks to all salmonid life stages are every bit as likely as the perceived benefits of a swifter smolt migration.

1. INTRODUCTION

The premise for flow augmentation is based on the argument that increasing water velocity increases smolt migration speed, which in turn improves smolt survival through reservoirs and at ocean entry. The purpose of this document is to examine key technical issues regarding the benefits of flow augmentation as a strategy for improving survival of downstream migrants. Reservoir drawdown, an alternative strategy for increasing water velocity through the mainstem Snake and Columbia rivers will also be examined. Data sets and analyses that pertain to Snake River stocks will be emphasized, particularly those stocks currently listed as threatened or endangered.

This document will focus on treating two smolt responses that can be useful in reflecting the effects of flow augmentation, or increased water velocity; travel time or migration speed, and survival. Although there has been recent interest in using migrational timing as a measure of flow effects (Marsh 1992), that response reflects principally the temporal initiation of the migration event, and does not provide a performance measure once fish are in transit between two locations. The latter is the focus of this manuscript.

1.1 SOCKEYE SALMON

Given the paucity of information, it is generally assumed, but has not been demonstrated, that sockeye show migratory responses consistent with those of yearling chinook and steelhead. The migratory characteristics of sockeye salmon within the Columbia Basin are poorly described, except for general run timing information at some dam index sites. Notably absent are any measures of migration speed or smolt survival. Only recently have travel time estimates for the Redfish Lake sockeye smolts become available. -Migrants have been PIT-tagged as they leave the lake, and travel time estimated to detection sites at Lower Granite, Little Goose and McNary dams. As yet those estimates have not been formally reported, only preliminary estimates have been presented to the Stanley Basin Technical Oversight Committee. Based on materials released at the 17 June, 1992 meeting, the general travel time to Lower Granite Dam was about 17 days. However, the observations are few, since only 79 fish were released in 1992. It is unlikely that there will be sufficient data to investigate flow effects for at least several years.

2. FLOW EFFECTS: HISTORICAL PERSPECTIVE

2.1 SMOLT TRAVEL TIME

Early investigations described the migratory characteristics of spring/summer yearling chinook and steelhead through the Snake and Columbia Rivers. Typically, travel time and/or survival estimates for the composite wild and hatchery populations were presented, particularly in regression analyses that included estimates from a number of years.

Impoundment of the Snake and Columbia rivers has decreased the migration speed of yearling chinook salmon and steelhead. Ebel and Raymond (1976) estimated that in 1973, yearling chinook salmon and steelhead took about 65 d to reach The Dalles Dam from trap sites on the Salmon River in Idaho. They suggested this was approximately twice the time required before dam construction. Bentley and Raymond (1976) also presented data that indicated migrations were delayed after impoundment. Following the installation of Lower Monumental and Little Goose dams on the Snake River, yearling chinook smolts took about twice as long to traverse the distance from release sites on the Salmon River to Ice Harbor Dam. During three years prior to impoundment, they estimated that yearling chinook migrated through the free-flowing reach to Ice Harbor Dam in 9 to 15 d.

NMFS investigators first provided evidence that the rate of migration through certain segments of the Snake and Columbia River was influenced by prevailing river discharge volumes. Sims et al. (1978) observed that during the dramatically low flows in 1977, yearling chinook traversed the reach from those same Salmon River traps to the Dalles in 57 d; whereas, in 1975 and 1976 Sims et al. (1976 and 1977) indexed travel time at 21 and 27 d, respectively, about half that observed in 1977 with the same numbers of dams in place. The authors characterized the two earlier years as above average flow years. These data sets provided the first quantitative treatment of the relationship of flow on smolt migration speed through'the hydroelectric system.

2.1.1 Annual Indices of Smolt Travel Time

Sims and Ossiander (1981) expanded the preceding data set and presented a synthesis of flow/travel time estimates for yearling chinook and steelhead for the years 1973-1979. They regressed annual indices of travel time against the flow at Ice Harbor Dam during the migration peak. The regression indicated that in years when flows were high, fish moved faster from the upper dam, either Little Goose or Lower Granite, to The Dalles Dam. They noted that the greatest change in travel time for both species was apparent at flows below approximately 100 kcfs.

The National Marine Fisheries Service continued reporting annual indices of travel time in the mainstem, through 1983 (Sims et al. 1984), but their last synthesis included only data acquired through 1982 (Sims et al. 1983). The Fish Passage Center has continued to add to this smolt travel time data set since 1984. Their last comprehensive synthesis was presented in the 1987 Annual Report (FPC 1988), for the years 1973-1987. The FPC authors fit a curvilinear function to the data that suggested travel time continues to decrease over the entire range of observed flows. Inspection of Figure 22 in that report indicates that pronounced changes in travel time are evident when flows were indexed below approximately 80 to 100 kcfs, whereas above those levels changes in travel time were less (Figure 1). Interpolating from their figure, for yearling chinook, the decrease in the average travel time per project, as flows increased from 100 to 160 kcfs, was approximately one day.

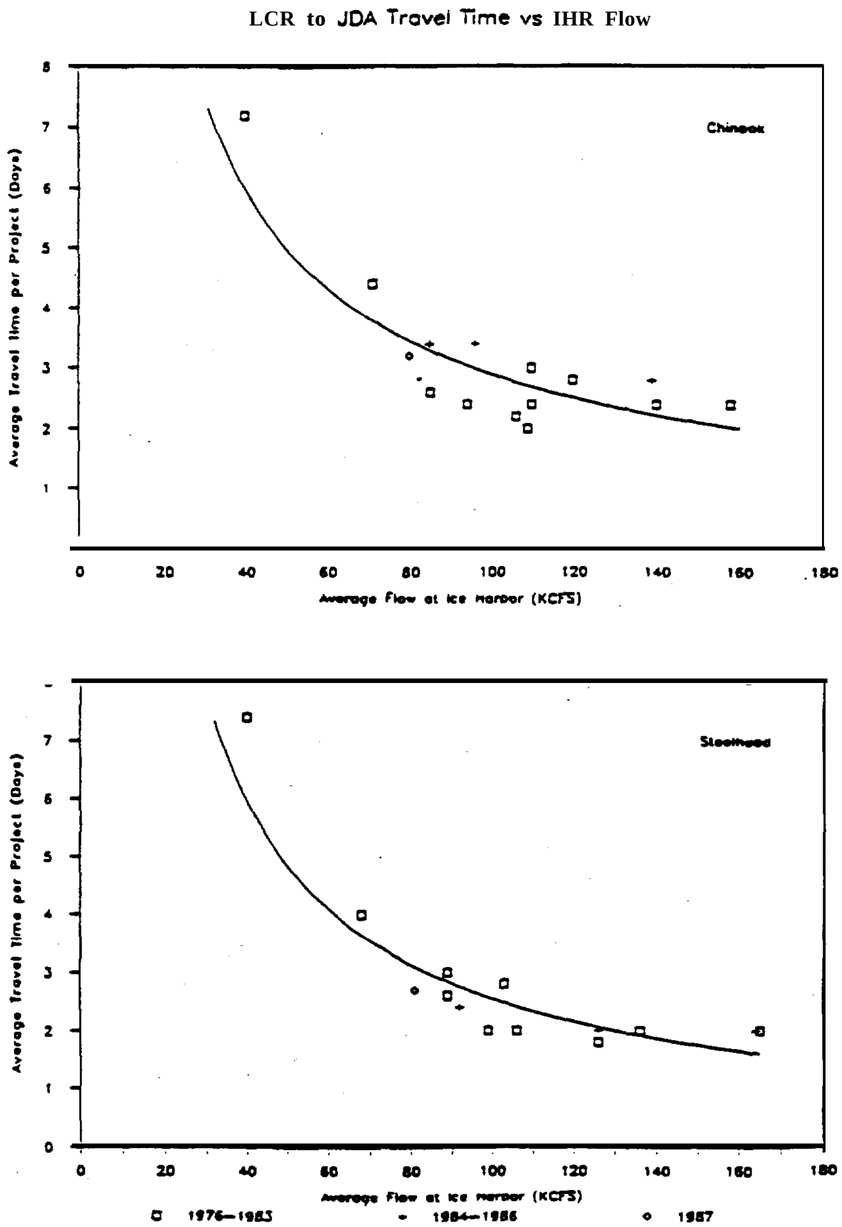


FIGURE 22. Relationship of Travel Time (per project) from Lower Granite to John Day for Yearling Chinook and Steelhead and Average River Flow at Ice Harbor, 1976 - 1987.

Figure 1. Flow travel time relationship from Lower Granite Dam to John Day Dam as reported by the FPC (1988). Each data point represents an annual average travel time estimate for each year's entire migrant population, and the flow index ascribed to each year's migration period. Figure was taken from FPC (1988).

Considering the general nature of the data and the unmeasured variability associated with each annual index, Chapman et al. (1991) chose to view the data in general terms. With respect to the currently prescribed fishery flow of 85 kcfs in the Snake River, they examined the trends in travel time at flows above and below that value. They noted that pronounced delay in chinook travel time was apparent in years when Snake River flows were indexed well below 85 kcfs. However, in years when flows were above that level, the rate of change in travel time diminished, amounting to less than a day decrease as flows increased from 85 to 160 kcfs (Chapman et al. 1991).

Obviously, these types of data are very general indices of travel time, with no measures of variance for either the dependent or independent variables. As such, they provide only a general assessment of travel time. Furthermore, the data do not assess potential effects of smolt development on migration rate, or other factors such as temperature or the amount of spill encountered during passage. Although, it could be argued that the effects of such factors are accommodated, or offset, by averaging across a broad representative sample of marked groups. However, the marked groups within any year often, but not entirely, consisted of hatchery stocks in the Salmon and Clearwater rivers. Apart from the other aforementioned limitations, they may not represent wild stocks. Nevertheless, I suggest these data sets may provide our most useful insight into the dynamics of smolt migration.

2.1.1.1 Predicting Travel Time: Downstream from LGR Dam.

Using these annual indices of travel time, (Table 1), I described the relationship to flow through the Snake River projects below Lower Granite Dam. I applied several mathematical models to the data set to reflect the different perspectives offered by some investigators, using the regression routine in the GB-STAT software. The exponential function for this data set as depicted in FPC (1988) was calculated to have a correlation coefficient of .82, for yearling chinook (refer to Giorgi 1991 for details). However, the model that yielded the highest correlation coefficient (.95) was a third order polynomial (see Giorgi 1991 for details). I used these two models to predict smolt travel times at 10 kcfs intervals from 40 to 140 kcfs (Table 2, Figure 2). These results are also compared with those predicted by the threshold-linear model of Chapman et al. (1991), discussed previously.

Table **1.** A compilation of flow, travel time andsurvival estimates for yearling chinook salmon migrating from the uppermost dam on the Snake River (Lower Granite or Little Goose) to either The Dalles or John Day Dam. Estimates are reported as an average per project. Data for the years 1973-1983 were taken from tables presented in Sims et al. (1983, 1984). Travel time and flow estimates for the years 1984-1987 were derived from data presented by FPC (1988).

Year	Mean flow (kcfs)	Travel Time (days) reach	Travel Time (days) per project	Survival (%) per project
1973	71	22	4.4	55
1974	158	12	2.4	82
1975	140	12	2.4	79
1976	110	15	3.0	79
1977	40	36	7.2	52
1978	106	11	2.2	85
1979	85	13	2.6	79
1980	110	12	2.4	82
1981	94	12	2.4	na
1982	120	14	2.8	76
1983	109	10	2.0	91
1984	150	13	2.6	
1985	86	17	3.4	
1986	97	18	3.6	
1987	80	16	3.2	

Table 2. Predicted yearling chinook travel time per project. Exponential and polynomial models were fit to all estimates appearing in Table 1. The linear model for flows above 85 kcfs was taken from Chapman et al. (1991). The Berggren and Filardo estimates were calculated from a flow/travel time model presented by those authors in a 1991 draft manuscript submitted to the ESA Record. The water particle travel time (WPTT) at minimum operating pool were calculated by USACE staff. This Table originally appeared in Giorgi (1991).

Yearling Chinook Travel Time					
Flow	WPTT	Exponential	Polynomial	Linear	Bergg. & Filardo
40	4.8	6.0	7.3	--	5.0
50		5.0	5.9	--	4.2
60	3.2	4.3	4.9	--	3.7
70		3.8	4.0	--	3.4
80	2.4	3.5	3.4	2.9	3.1
90		3.2	3.0	2.8	2.9
100	1.9	2.9	2.8	2.7	2.7
110		2.7	2.6	2.7	2.6
120	1.6	2.5	2.6	2.6	2.5
130		2.4	2.6	2.5	2.4
140	1.4	2.2	2.7	2.5	2.3

Flows were converted to average water particle travel time (WPTT) from LGR Dam to the mouth of the Snake River, using data provided by USACE staff. Predicted water travel times were based on minimum operating elevations for the years the smolt travel time data were collected.

Regardless of the model, the predicted smolt travel times are quite similar at per project WPTT above approximately 2.2 d, or 90 kcfs. The greatest difference among the three models in this range of flow is .5 days at 140 kcfs/1.4 d WPTT (Figure 2, Table 2).

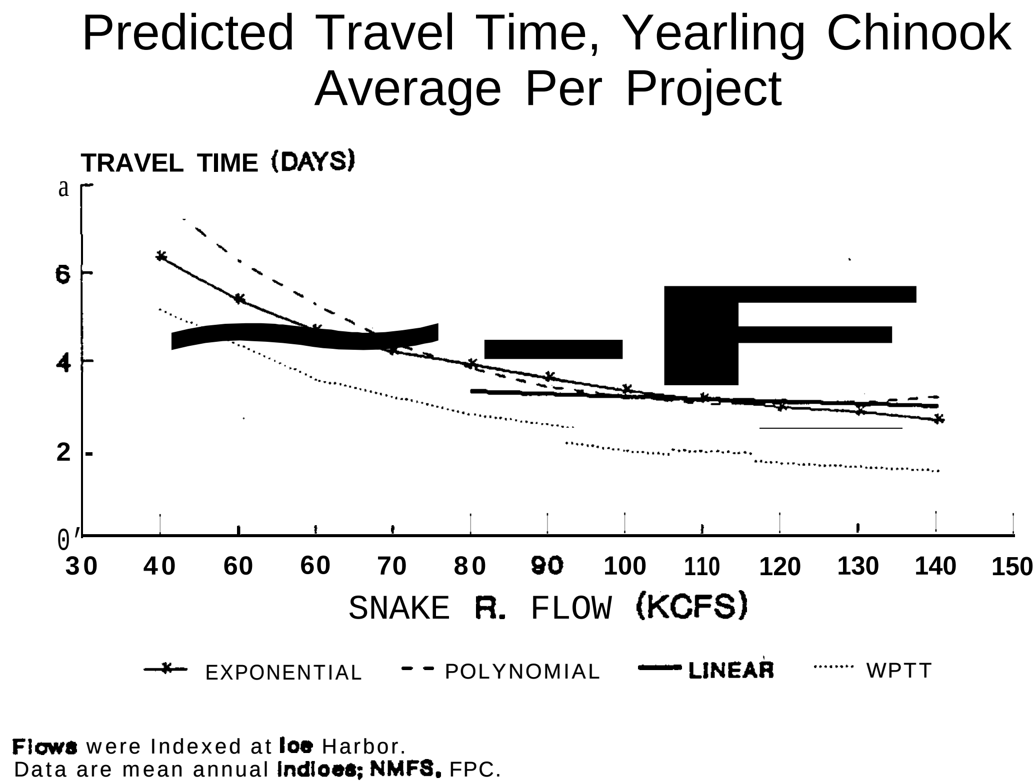


Figure 2. Three different mathematical fit to the same data set of smolt travel time and flow indices, see Table 1. Figure was taken from Giorgi (1991).

As a further basis of comparison, the relationship derived by Berggren and Filardo (1991) as depicted in the CBFWA flow proposal was used to calculate travel times. (Refer to previous passages in this report for details regarding their analysis.) Even though their relationship was developed from different types of data, the predicted smolt travel times at flows above about 90 kcfs/2.2 d WPTT are consistent with predictions of the models based on annual indices of travel time (Table 2).

Since some of these data sets are recognized to be general and/or with limited statistical foundation, no single model can be readily identified as the best, or most accurate. I recommend using both the polynomial, and the Berggren & Filardo models to bracket the potential range of response at a given water velocity.

The polynomial model becomes nearly asymptotic as flows increase. This suggests that changes in smolt travel time are nearly indiscernible above about 90 kcfs/2.2 d WPTT. In contrast, the Berggren & Filardo model predicts further decreases in travel time above this level, but the change between 90 and 140 kcfs only equates to .6 days per project. At flows less than about 90 kcfs both models show the confusing rate in change of travel time increases substantially relative to flows above 90 kcfs. However, the polynomial model predicts much longer travel times at low flows/water velocity, i.e., it predicts slower migration speed at low flows, than does the Berggren and Filardo model.

In general, all of the models predict similar smolt travel time at flows above approximately 90 kcfs. Collectively, the models indicate that at flows above 80 to 100 kcfs (WPTT 1.9 to 2.4 days), the decrease in smolt travel time is slight, ranging in the extreme from .1 to .8 days per project over the range of WPTT examined (Table 2).

2.1.1.2 Steelhead Travel Time

Inspection of Figure 1, taken from FPC (1988) reveals that steelhead move through the mainstem impounded Snake River at a nearly the same rate as chinook, at a given flow. Berggren and Filardo's (in press) analysis shows a similar trend, except that steelhead generally traverse the entire system, from upper to lower dam, 3 d faster than chinook.

In summary, both species traverse the reach from the upper dam on the Snake to the lower Columbia River sampling site (John Day or The Dalles) faster in years with higher flows, and generally migrate at about the same speed in any year, Furthermore, when flows are less than 80 to 100 kcfs, the rate of change in travel time increases substantially. Above those levels the rate of change in migration speed lessens, amounting to no more than one day per project as flows increase to 140 kcfs, regardless of the data set examined, or the model used to describe it.

2.1.1.3 Migratory Mechanics

The preceding characterizations of smolt travel time and river discharge have prompted regional fisheries managers to identify smolt migration in the Snake/Columbia River system as generally a passive process where migrants are passively swept downstream at rates dictated by water velocity (CBFWA 1991, Berggren and Filardo in press). This perspective probably overly simplifies the migratory behavior for the different species in the basin. Observations on sockeye indicate that a different process may occur in the impounded reservoirs. Burgner (1992) summarized the studies of several authors. He notes that smolts leaving a lake orient downstream and swim faster than the current in areas where the flow is uniform and slow. However, they turn and pass downstream tail first in areas of turbulent water. Although migrations through impounded reservoirs have not been investigated in such detail, it is reasonable to surmise similar behaviors would occur. Similar detailed observations for other Snake River species in reservoir environments are lacking.

2.2 SMOLT SURVIVAL

Smolt survival estimates accompanied the NMFS annual travel time indices. The system'survival estimates were calculated and reported by NMFS on an annual basis throughout part of the 1960s, most of the 1970s, and early 1980s. Raymond (1979) reported the system survival estimates for the years through 1975, and Sims and Ossiander (1981) reported the estimates for the years 1973 through 1979. Annual system survival estimates, or indices, represented the overall smolt survival from the upper dam on the Snake River to a lower Columbia River sampling site, either John Day or The Dalles dams, and reflect the combined effects of dam passage and reservoir residence.

Sims and Ossiander (1981) first developed the relationship between survival and prevailing flow volumes and provided the most detailed treatment and discussion. They noted that for the years they analyzed, 1973-1979, as the annual indices of flow increased, corresponding increases in migration rate and survival were observed. However, they also noted that increased spill volumes accompanied the increases in flow, and suggested that survival benefits accompanying increased flow may be due in large part to spill passage. Subsequently, the data set was expanded (COFO 1982), and most recently by Sims et al. (1983) (Figure 3). These data were the basis for identifying the currently prescribed minimum flows for fish protection; 85 kcfs at Lower Granite Dam and 220 kcfs at McNary Dam.

Raymond (1979) reported survival estimates for specific segments of the Snake and Columbia River. These data provide a more detail perspective of survival dynamics, but have been largely ignored in the subsequent development of reservoir mortality/flow relationships (this topic will be treated elsewhere in this report).

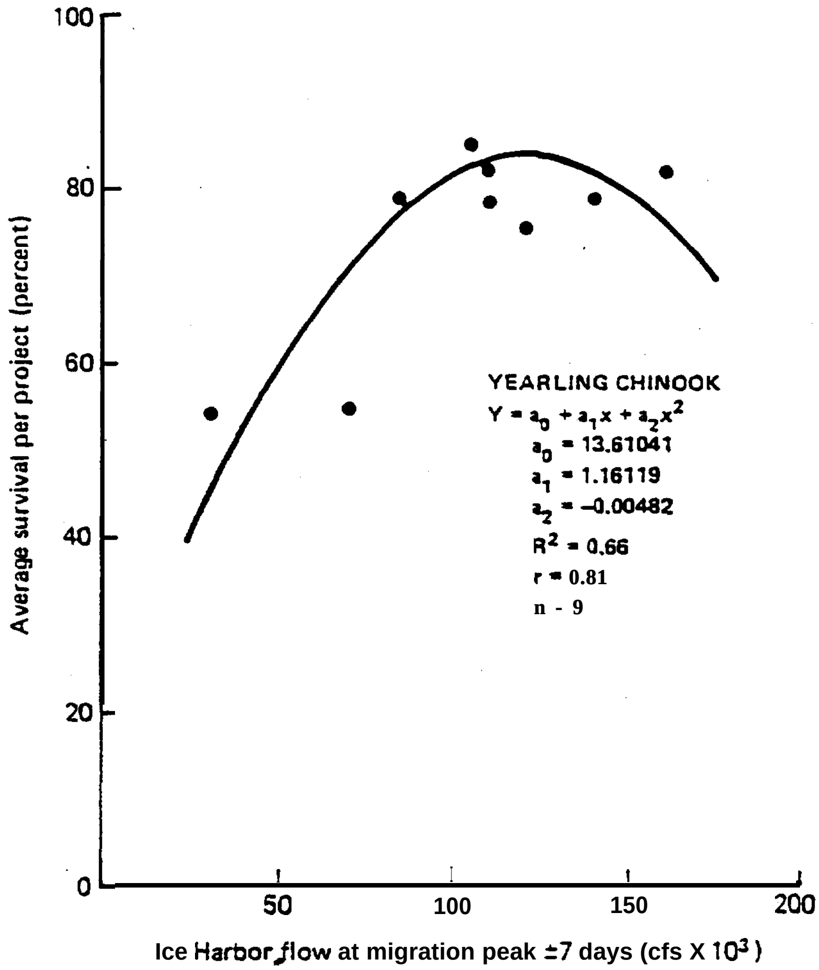


Figure 3. Annual estimates of smolt survival (yearling chinook) expressed as a function of a flow index for the migration period, as presented, in Sims et al. (1983). This is the expanded Sims and Ossiander data set that is often referred to, and has been used as the foundation for deriving reservoir mortality/flow relationships.

The reliability and relevance of these historical system survival estimates in today's river system has been questioned by a number of parties. The estimates lack statistical properties, i.e., measures of precision or assessments of accuracy were not provided, in part due to limitations associated with sampling and the estimation protocol. In fact, this was such a concern that efforts to continue producing smolt survival estimates in the mainstem were abandoned by the fisheries agencies, due to skepticism regarding their utility. This is underscored by the fact that during the 1980s, travel time replaced survival as the key performance measure for juvenile passage. The extent to which water velocity, as indexed by river discharge volumes (flow), influenced the speed of smolt migration became a central issue. As yet, the relationship between migration speed and survival has not been adequately quantified.

Furthermore, the only available survival estimates were acquired during the 1970s when conditions, both physical and biological, were notably different from the contemporary system. During the last decade, numerous bypass systems have been emplaced or upgraded, and spill and flow augmentation programs have been implemented. If these efforts are as effective as some purport, then the system should be more benign than it was during the 1970s. Also, the population of migrants is different, the complement of hatchery and wild fish has changed. Today hatchery fish occur in higher proportions than was the case during the 1970s. No doubt the processes affecting smolt survival through today's system differ from historical dynamics, and expectedly so will the magnitude of survival.

These concerns and uncertainties emphasize the need to evaluate smolt performance as they transit the system today. Efforts to measure the magnitude and location of smolt mortality should proceed expeditiously.

3. FLOW EFFECTS: CURRENT PERSPECTIVES

3.1 RESERVOIR MORTALITY/FLOW RELATIONSHIP

Factors in addition to speed of migration, affect smolt survival as they migrate through the hydro-system. Project impacts associated with turbine, spill and bypass passage, as well as environmental conditions apart from flow, are also reflected in the historical annual system survival estimates. Thus, expressing system survival in terms of flow alone, ignores other potential sources of mortality which may in themselves vary from year to year. To rectify this shortcoming, and more reasonably reflect effects of migration speed on smolt survival, another index, reservoir mortality, was derived.

During the late 1980s the fisheries community suggested that estimates of reservoir mortality would presumably reflect mortality associated with speed of migration, apart from direct dam passage effects. However, no direct estimates of reservoir mortality were, or are, available. Estimates had to be indirectly derived from the existing historical NMFS annual system survival indices, described previously.

To accomplish this, the effects of dam-related mortality in each year's system survival index had to be estimated, and the system estimate adjusted accordingly; the residual estimated effects were presumed to reflect mortality associated with reservoir processes. The resultant annual index of reservoir mortality was then apportioned evenly throughout the system and typically expressed per unit mile (McConnaha 1990). These annual reservoir mortality estimates were expressed as a function of a flow index, or smolt travel time index, for each year's migration period. Estimates from the years 1970, 1973-1979, and 1980 have been selected by some analytical groups to construct the relationships (Figure 4). Relationships have been derived for two species, yearling chinook and steelhead, and are key drivers for most passage models employed in the region, including PAM/SPM, FLUSH/ELCM and CRiSP.O/SLCM.

3.2 DERIVING RESERVOIR MORTALITY ESTIMATES

The means by which dam-related mortality was estimated each year is important, because it alone determines how much mortality would be attributed to reservoir processes. Since direct measures of dam mortality were not available at individual dam sites, presumed standard estimates of passage route-specific mortality were applied at each dam site. Depending on the proportion of water spilled and presumed spill passage efficiency, and the estimated fish guiding efficiency, estimates of the proportion of the smolt population passing each of the three pathways (turbine, spill and bypass) were calculated. Standardized estimates of pathway-specific mortality were applied to those proportions and an indirect systemwide estimate of dam mortality could be produced for each of the ten years comprising the relationship.

The extent to which this derivation procedure approximates actual dam-related mortality, and associated reservoir mortality has been questioned by some investigators. Giorgi (1992) contends there are large discrepancies between the assumed dam-related effects and actual direct measures provided in some years. For example, during the 1973 outmigration Raymond et al. (1974) estimated that only 50% of the yearling chinook in the Little Goose forebay survived to the tailrace of that dam (at that time the uppermost dam on the Snake). In the NPPC derivation of the reservoir mortality estimate for that year, only the presumed 15% turbine mortality estimate was used for that site. As a result, dam effects were understated and reservoir effects were overstated. Thus, by relying on generalized, indirect measures of reservoir mortality, important details regarding the location and magnitude of mortality have been lost, and perhaps more importantly, mechanisms causing smolt mortality may be mischaracterized.

To further illustrate this point, a comparison of survival estimates for both yearling chinook and steelhead is instructive. The system survival estimates from the upper dam on the Snake to the lower dam on the Columbia River for these species is similar in any year (Table 3), and so are the derived reservoir mortality estimates. However, inspection of Raymond's (1979) estimates reveals that the survival of each species through just the Snake River was dramatically different in most years (Table 4). Overall, across all years, steelhead survived at about twice the rate of chinook through

FIGURE 3-17

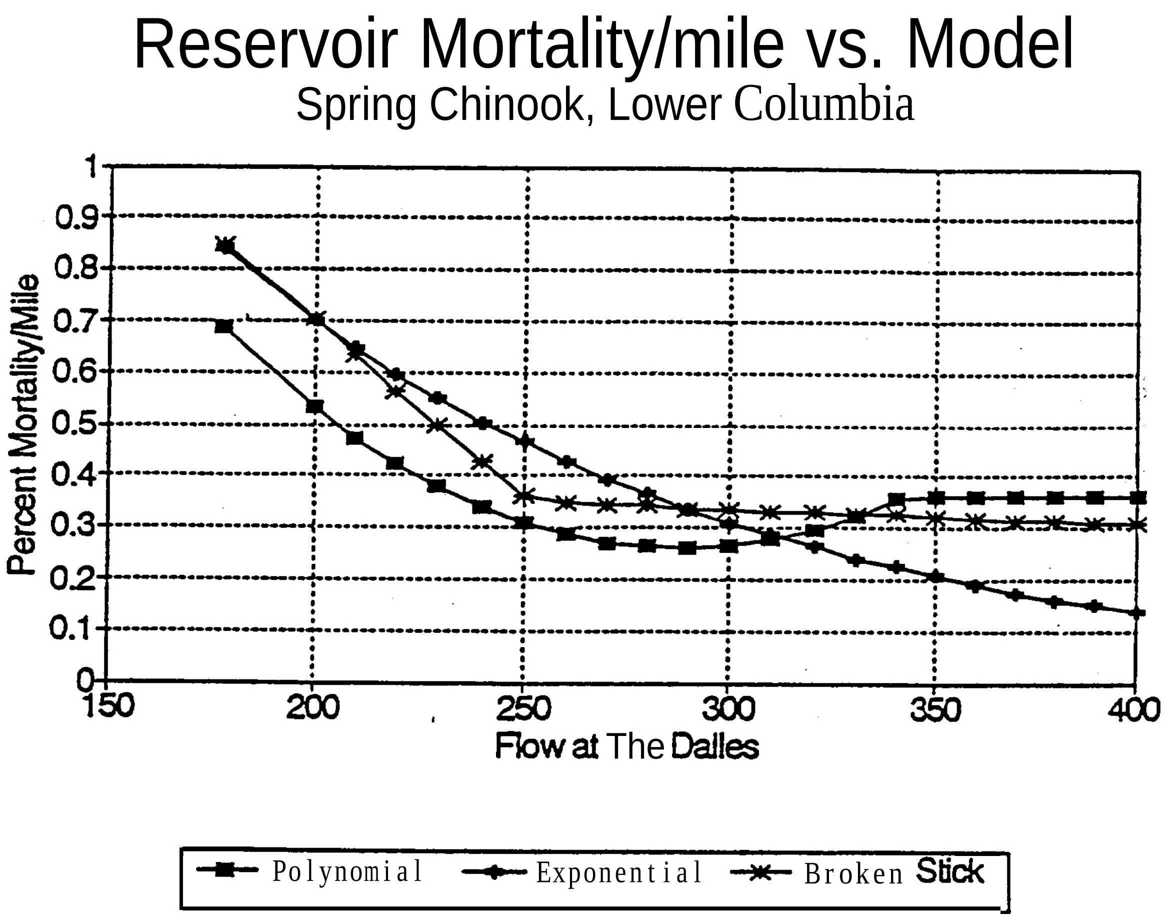


Figure 4. The reservoir mortality models used as drivers in the Northwest Power Planning Council Smolt Passage Model (PAM). Figure reproduced from SOR Screening Report (1992).

DATA BASE FOR RESERVOIR SMOLT SURVIVAL

SPRING CHINOOK

YEAR	NO. PROJECTS	MILES	MAY FLOW TDA	MAY n o w IHR	OBSERVED SYSTEM SURVIVAL (a)	ESTIMATED SYSTEM DAM SURVIVAL (b)	ESTIMATED SYSTEM RES SURVIVAL (c)	RES MORT PER MILE (d)
70	5	203	258	99	0.22	0.70	0.31	0.0057
72	5	203	341	126	0.15	0.66	0.23	0.0073
73	5	203	140	54	0.05	0.57	0.09	0.0110
74	5	203	341	133	0.40	0.68	0.59	0.0026
75	6	240	286	114	0.25	0.63	0.40	0.0039
76	6	240	324	141	0.24	0.68	0.36	0.0043
77	b	240	128	38	0.02	052	0.04	0.0136
78	6	240	250	95	0.37	057	0.64	0.0018
79	6	240	223	90	0.24	0.55	0.44	0.0034
80	6	240	234	102	0.30	0.57	0.53	0.0026

STEELHEAD

YEAR	NO. PROJECTS	MILES	MAY FLOW TDA	MAY FLOW IHR	OBSERVED SYSTEM SURVIVAL (a)	ESTIMATED SYSTEM DAM SURVIVAL (b)	ESTIMATED SYSTEM RES SURVIVAL (c)	RES MORT PER MILE (d)
70	5	203	258	99	0.38	0.703	0.54	0.0030
72	5	203	341	126	020	0.656	0.30	0.0059
73	5	203	140	54	0.05	0.574	0.09	0.0120
74	5	203	341	133	0.23	0.68	0.34	0.0053
7s	6	240	286	114	0.42	0.63	0.67	0.0017
76	6	240	324	141	0.29	0.67	0.43	0.0035
n	6	240	128	38	0.01	052	0.02	0.0165
78	6	240	250	95	024	0.57	0.42	0.0036
79	6	240	223	90	0.12	0.55	Or,	0.0063
80	6	240	234	102	0.14	0.57	0.25	0.0058

(a): Sims and Ossiander, Raymond, Sims et al.
(b): SPM Spreadsheet calculator with actual spill and bypass situations
(c): (a) / (b)
(d): -ln(c)/Miles

NPPC:WEM:061190

Table 3. Survival estimates reported by McConnaha (1990) as used in the development of the reservoir mortality/flow relationships in the NPPC passage model, PAM. Since this reporting, the 1972 data have been removed from the data set.

TABLE 11.—*Survival of juvenile chinook salmon and steelheads from the upper dam (Snake River) to The Dalles Dram. 1966 to 1975.*

Year	Upper dam to ICC Harbor Dam		Ice Harbor Dam co The Dalles Dam		Upper dam to The Dalles Dam	
	Chinook salmon %	Steelheads %	Chinook salmon %	Steelheads %	Chinook salmon %	Steelheads %
1966			63	75	65	73
1967			64	37	64	37
1968			62	60	62	60
Avenge 1966–1968			63	64	63[c]	64[d]
1969	73	85	62	42	56	36
1970	33	80	67	48	22	38
1971	48	80				
1972	39	60	42	33	I3	20
1973	12	27	42	15	3	4
1974	50	78	71	25	34	20
1975	36	74	69	53	23	34
Average 1970–1975	36[a]	67[b]	58[a]	36[b]	20[c]	23[d]

[a] Significant difference in survival of chinook salmon between upper and lower stretches of river: $t = 4.154$: df = 4: $P < 0.02$.

[b] Significant difference in survival of steelheads between upper and lower stretches of river: $t = -4.263$: df = 4: $P < 0.02$. Note: minus value for t is due to higher survival in upper river.

[c] Significant difference in survival of chinook salmon between pre-dam (1966–1968) and post-dam (1970–1975) period: $t = 5.66$: df = 6: $P < 0.001$.

[d] Significant difference in survival of steelheads between pre- and post-dam period: $t = 3.64$: df = 6: $P < 0.01$.

Table 4. Data Table from Raymond (1979).

the Snake. But, in the Columbia River the patterns were reversed, chinook survived at about twice the rate as steelhead. The species did not appear to be equally affected by reach-specific conditions. A plausible conclusion could be that although the two species survived at about the same rate while traversing the entire system, they were affected by different mechanisms of mortality en route. This issue is completely obfuscated by the process that has been used to derive reservoir mortality estimates. I emphasize that current reservoir mortality estimates are presumed, not measured values.

These examples reflect the obvious uncertainty and severe limitations regarding existing regionally-correct reservoir mortality estimates, as well as any relationships and predictions developed from them. Acquiring reliable estimates of smolt survival with today's complement of facilities, water management strategies, and stock/species structure is necessary if we are to have any confidence in the predictive capabilities of models that require these estimates as drivers.

3.3 ADULT RETURNS AS MEASURES OF FLOW EFFECTS

Petrosky (1991) examined the relationship between survival from smolt to returning adult and prevailing flow volumes in the Snake River at the time of smolt migration. For the years 1977-1987, he estimated the smolt to adult return rate (SAR) for two populations of spring chinook,; Rapid River Hatchery and a wild population in Marsh Creek. He described the relationship between each year's SAR and indices of flow during the outmigration period, and found them to be positive for both populations. The wild population exhibited higher SARs overall. He concluded:

> "The positive relationships found between smolt migration flow and the recruitment and return rate of Marsh Creek wild and Rapid River Hatchery spring chinook tend to corroborate the flow-smolt survival relationships developed by Sims and Ossiander (1981). . . . . Poor returns should be expected following years with poor migration velocity."

He provided discussion that linked migration and water speed, and identified mortality mechanisms that may be sensitive to changes in speed.

This perspective attributes changes in the SAR to a single variable, flow, used as a surrogate for smolt migration speed. Although the author acknowledges numerous other variables from the natal tributary through ocean residence can affect survival, he suggests these mechanism are sources of variability and collectively responsible for the noise associated with the relationships. In my view attributing adult return rates to any single variable is problematic, or rather impossible. The following example illustrates my concern.

During the years considered in the preceding analysis, spill frequently occurred throughout the Snake River and in the Lower Columbia River. More importantly, spill levels exhibited a positive relationship with flow. Table 5 and Figure 5 show the relationship between the average daily spill at both Ice Harbor and Lower Granite Dam, during the month of May and Snake River flow indices calculated by Petrosky (1991); they exhibit strong colinearity.

Table 5. Smolt to adult return rate (SAR) and Snake River flow indices for the period 20 April through 30 May are from Petrosky (1991). Average daily spill volumes for the month of May were calculated from USACE annual Fish Passage Reports.

	SAR		Flow	May Spill (KCFS)	
	Marsh Cr.	Rapid R.	(KCFS)	IH	LGR
1977	.01	.03	40.2	0	0
1978	.23	.14	95.8	16.8	8.3
1979	.12	.26	89.9	25.4	4.5
1980	.05	.21	102.9	23.2	0
1981	.21	.06	86.7	17.8	8.8
1982	1.64	.13	131.6	61	35.6
1983	.36	.44	111.3	52.5	19.6
1984	.65	.33	146.1	27.0	45.5
1985	1.34	.33	87.2	11.2	2.2
1986	.17	.34	105.7	46.1	8.6
1987	.10	.11	62.4	< 1	0

Spill is considered to the most benign route of passage for downstream migrants. Since both water speed and spill increased with flow, regression analyses treating either, or both variables are confounded. Even if the SAR were presumed to be an appropriate measure reflecting primarily inriver migration effects (a position I do not hold and will address below), it would be impossible to attribute effects to either single variable in this example. An appropriate conclusion could be, (if all other sources of mortality affecting each cohort were equivalent every year) that the total condition, increased speed and spill, was beneficial.

The relationships do suggest that in years (1977 and 1987) of no spill and extremely low flows (as indexed from 40 to 62 kcfs) subsequent SARs were the lowest estimated for both populations. This suggests that very poor passage conditions may have a pronounced effect on subsequent adult returns and it would be prudent to avoid those conditions when they periodically occur. However, at flows and spill levels above those levels, the recruitment patterns and relationships of the two populations are inconsistent. This is evidenced by the fact that there was no correlation between Rapid River and Marsh Creek SARs; $r=0.18$, $p=0.61$ (Figure 6).

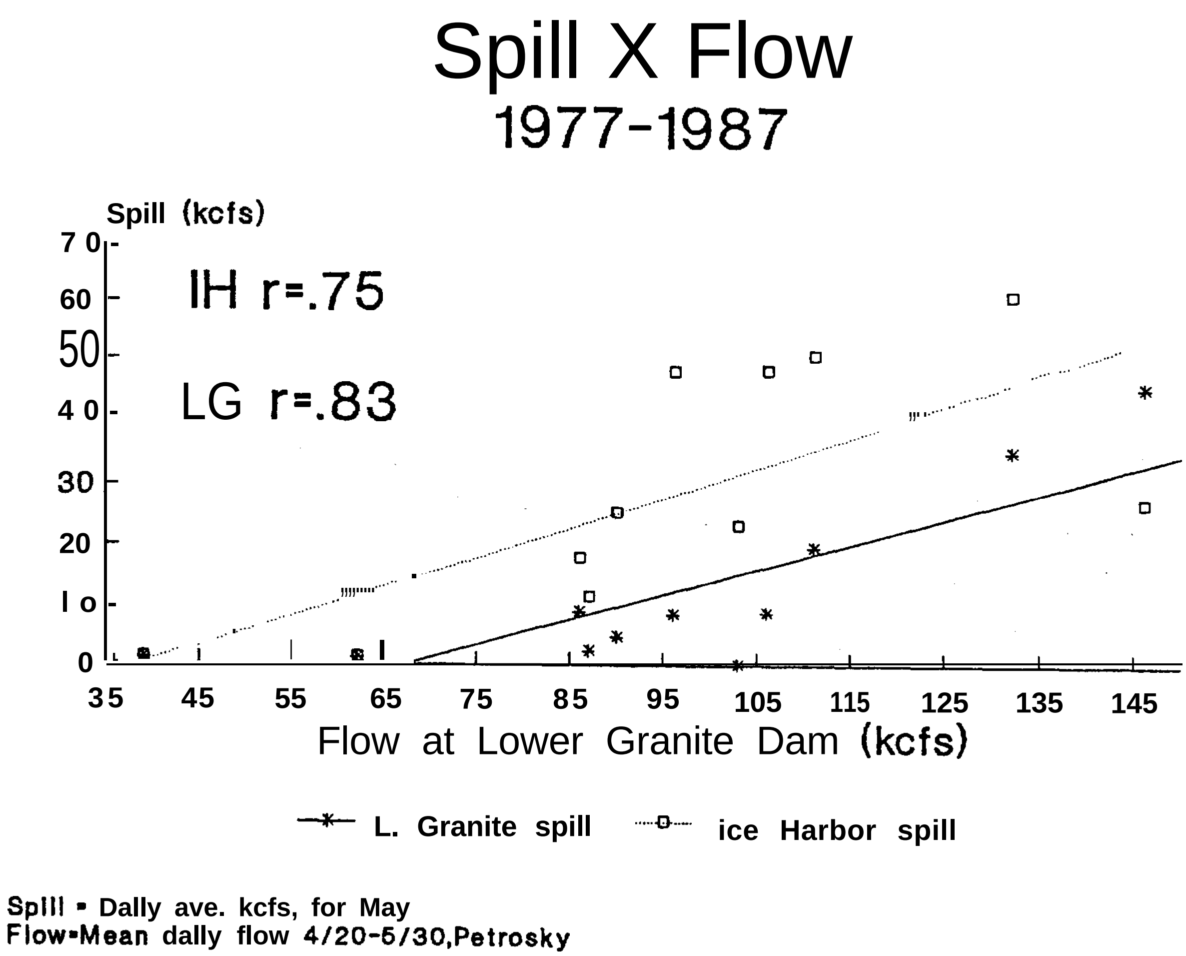


Figure 5. Spill versus Flow; Ice Harbor and Lower Granite Darn 1977-1987.

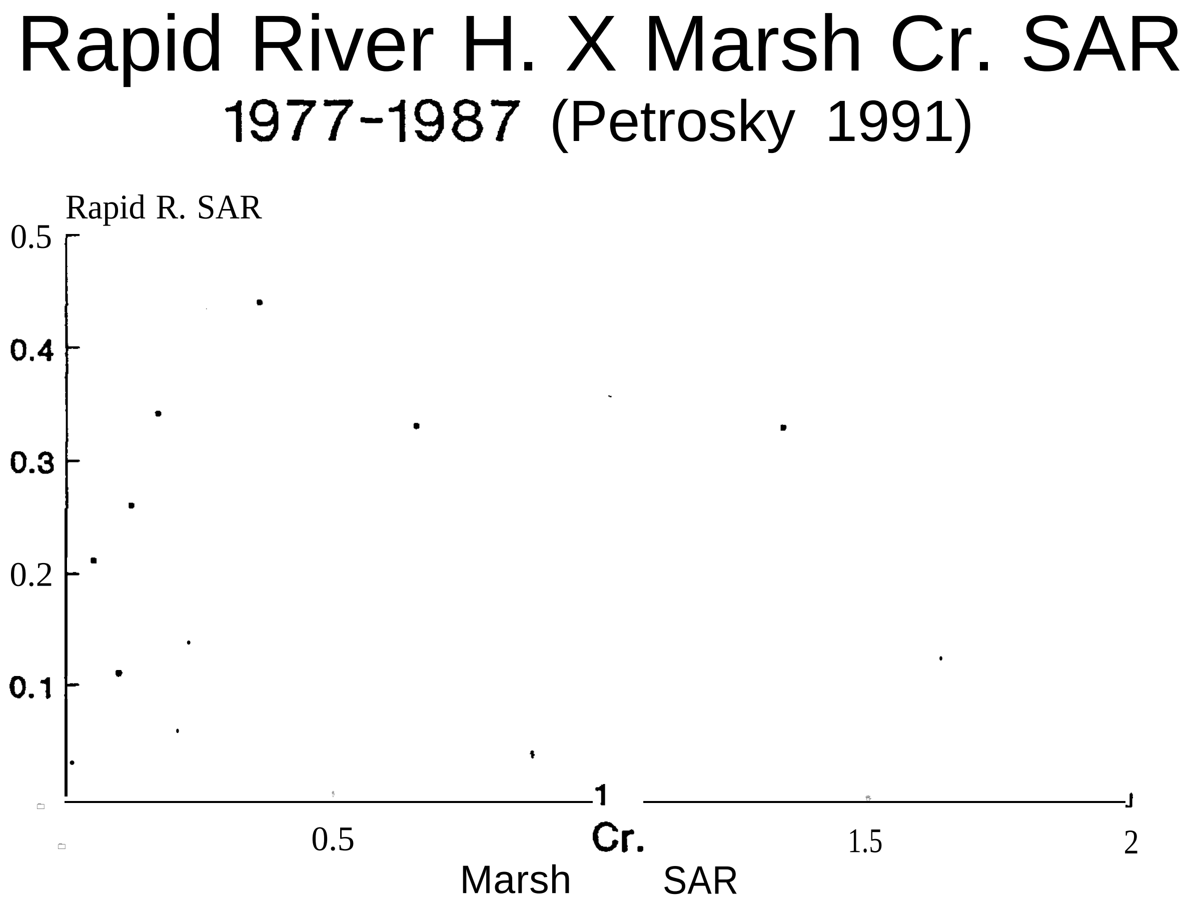


Figure 6. Marsh Creek versus Rapid River Hatchery SAR.

This distinction between spill and flow effects is important because they are two very different mechanisms of mortality, that are mitigated in different manners. For example, if fish actually benefitted more from spill than water speed, then management programs that emphasize increasing water speed, rather than spill passage, are misplaced. Given this scenario, even during low flow years benefits could be realized by increasing the spill rate, rather than attempting to increase the speed of migration. Moreover, the Marsh Creek analyses cannot resolve the confounding effects of these two variables.

Furthermore, there are numerous other variables that remain unquantified and affect the estimated survival to adulthood for any index populations. Apart from conditions experienced during downstream migration, the proportion of the index population transported as smolts, prevailing estuarine and marine conditions, as well as passage conditions encountered by returning adults in the mainstem and through the tributaries all influence survival to the spawning ground or hatchery. The comparison of SARs for Rapid River and Marsh Creek illustrates this point. If flow were the dominant mechanism affecting survival to adulthood, the SAR of both populations should rise and fall in unison, in response to prevailing annual flow conditions. Such a pattern is not apparent (Table 5, Figure 5); there is no correlation between the SARs for these populations; $r=0.18$, $p=0.61$.

It is unrealistic to expect that it is possible to employ these types of analyses of adult return data to demonstrate and quantify the effects of any single variable. More direct measures of performance in immediate response to passage conditions are required, e.g., smolt survival within the reach of interest during the prevailing flow or passage condition (Skalski and Giorgi 1992).

3.4 MECHANISMS OF MORTALITY ASSOCIATED WITH MIGRATION DELAY

3.4.1 Predation

The principal mechanism responsible for mortality associated with migration speed appears to be predation by predatory fish. It is reasoned that migrational delay increases exposure time to predatory fish within the reservoirs. A separate but related issue is that increased water velocity may also disperse predators staging in the tailrace areas and reduce their feeding efficiency (Poe 1992). Northern squawfish are the most effective predators in the system. For example, Rieman et al. (1991) estimated that 2.7 million juvenile salmon were consumed annually. in John Day Reservoir, during the years 1983-1986; and squawfish were responsible for 78% of that loss. Since squawfish consume both live and dead smolts (Poe 1992), consumption does not directly equate to predator caused mortality, nevertheless current system-wide estimates of consumption (Shively et al. 1991) indicate the mortality is substantial and pervasive throughout Snake and Lower Columbia River reservoirs. However, recent research has indicated that squawfish prefer dead juvenile chinook to live ones (Gadomski and Hall-Griswold 1992). Thus, previous estimates of predation mortality, derived from consumption rate information, may be too high.

3.4.1.1 Modeling **Predation**

Direct measures of changes in predation-related smolt mortality associated with either specific flow volumes, or smolt migration speed, are not available. Investigators have relied on computer models to simulate such mechanisms and attempt. Two such models are the Columbia River Ecosystem Model (CREM) and the Columbia River Passage Model (CRiSP.l). The latter simulates smolt passage through the entire system and is the most appropriate to consider regarding discussions of overall smolt passage mortality. The model combines predator population estimates, consumption rates, seasonal temperature profiles and smolt velocity as influenced by water velocity and behavior associated with stage of development, to predict mortality attributable to predatory fish. In the model, predation is one of two primary mechanisms that affects smolt mortality in the reservoirs, the other is gas saturation, which becomes problematic at high levels of spill associated with elevated river discharge. As with other passage models there is considerable uncertainty regarding input values, and so necessarily the accuracy of the output.

3.4.2 Residualism and Related Concerns

It has been suggested that prolonged intiver residence associated with delayed migration may increase the risk of disease transmission, residualism, and depletion of forage items. Although intuitively appealing, there is little qualitative or quantitative evidence to support these concerns. Steelhead do commonly residualize in the system, and there is laboratory evidence that suggests temperatures'in excess of 54 degrees F may cause reversion from smolt to parr (Zaugg and Wagner 1973). Furthermore, it is plausible that if migration is too slow, steelhead smolts could be exposed to seasonally increasing water temperatures, thus increasing the risk of residualization. However, such mechanisms have not been documented for either chinook or sockeye salmon, the species of interest under ESA. But, Mullan et al. (1992) suggest that residualism may be a common behavior for precocious male chinook in the Columbia River. Their proclivity to reside instream rather than migrate seaward is associated with precocious sexual maturation rather than environmental conditions in the migration corridor.

3.4.3 Biological Window

Apart from mortality incurred during passage through the hydrocomplex, it has been suggested that migrational delay impairs survival at seawater entry. The Columbia Basin Fish and Wildlife Authority (1991) developed this argument in their Flow Proposal.

The central premise in that document is that smolts are passively swept seaward, and historically, the timing of seawater entry was dictated by the hydrographs in the Snake and Columbia rivers and synchronized with a "biological window". They argue that dam construction has altered the hydrography, disrupted the timing of ocean entry and diminished the probability that smolts can enter the biological window, implying that this period is of limited duration and well defined. Intuitively, this ecological theory is appealing. However, biological information is largely anecdotal.

The theoretical window has two aspects; the physiological preparedness of the smolts for seawater entry, and the ecological condition of the estuarine and nearshore marine waters in terms of productivity, competition, and predation. However, our understanding of the requirements for smolts is poor, and assessments of their performance in estuarine and nearshore marine waters are lacking.

3.4.3.1 Smolt Development and Seawater Entry

There is evidence that steelhead lose salinity resistance during the summer (Wagner 1974), after their normal spring migration period. As noted earlier, steelhead do residualize within the mainstem Columbia and Snake Rivers. However, laboratory evidence suggests temperatures in excess of 54 degrees F may cause the reversion (Zaugg and Wagner 1973), rather than merely age of the fish. It is plausible that if migration is too slow, steelhead smolts could encounter increasing summer water temperatures. The effects of temperature on stimulating steelhead smolts to residualize suggests they should egress from riverine waters before critical temperatures are reached. Such a mechanism is not documented for chinook salmon.

Contrary to conventional wisdom there is no convincing evidence that migrational delay of chinook impairs seawater adaptability. In fact, with respect to chinook, Hoar (1976) notes;

> "This species, unlike the coho or steelhead, acquires high salinity resistance gradually while in fresh water without any sharp increase associated with a smolt transformation."

Inspection of figure 8 in his paper emphasizes this point. He presents a graph plotting the % survival over a 30-d period following seawater entry as a function of fish age; differences between chinook salmon and steelhead are readily apparent. Steelhead survival drops off sharply from nearly 100% to near 0%, whereas chinook survival continued to increase with the age of the fish. Healey (1991) also notes the plasticity of chinook with regard to their ability to adapt to seawater over a broad range of life stages. Based on the assessments of these investigators there is no evidence supporting the theory of a physiologically based, time-constrained window for chinook salmon.

Sockeye salmon do exhibit annual cycles in seawater adaptability. How-ever, the time-frame over which they are fully adaptable to seawater appears quite long. Foote et al. (1992) found that yearlings of the anadromous form of sockeye from a British Columbia population showed increased adaptability to seawater by late March. By late April they were fully tolerant of seawater, and remained so at least through early. August. The findings indicate that sockeye have a broad temporal opportunity for entering and successfully adapting to seawater, and suggest that moderate delay in downstream migration may not impair performance. Similar investigations have not been conducted for either Snake or Columbia River sockeye populations. In light of Foote et al. (1992) findings such studies may be warranted.

3.4.3.2 Marine Conditions

With respect to the need for species to target seawater entry to coincide with optimum conditions in the estuarine environment, the migrational characteristics of several stocks of salmon suggest that if there is a biological window it is broad, and like many biological processes that are production-based, will vary in timing and intensity from year to year. The stocks I am referring to exhibit protracted migrations spanning several months.

Subyearling chinook salmon, including both summer and fall races, egress from the Columbia Basin from late spring through much of the summer and continue to trickle out well into fall. These patterns are well documented in both NMFS and FPC reports. Furthermore, these patterns were evident over three decades ago, when only Bonneville and Rock Island dams were in place (Chapman et al. 1991), and are consistent with observations made by Mains and Smith (1964), as well as Rich (1922) for years prior to dam construction.

Yearling chinook in the Snake River drainage also exhibit protracted migrations. In 1989 and 1990, wild stocks of summer chinook from the Snake River system have been observed passing LGR Dam in mid-April for the last two years. Wild spring stocks from the same system migrate later, continuing into July (Matthews et al. 1990 and Chapman et al. 1991). The timing of these yearling chinook is consistent with observations made by Raymond in 1966 and 1967 at Ice Harbor Dam, then the uppermost dam on the Snake River. These observations do not suggest that timing of ocean entry has ever been synchronized with specific temporally constrained conditions in the marine environment; rather, juvenile salmonids entered the Columbia River estuary continually throughout the spring and summer and into the fall.

3.4.3.3. Research

To date, there has been no research directed at identifying such a physiological window for chinook stocks in the Columbia and Snake River. Specifically, there have been no experiments to indicate decreased survival is associated with progressive delayed entry into seawater. Until effects on survival are demonstrated and relationships developed it will not be possible to determine whether migration speed is important in this regard, or if it is, how brief a delay is necessary to ensure adequate survival at seawater entry. It would appear that research on this topic is warranted, if arguments regarding the existence and importance of this mechanism persist.

3.5 PULSING

Inspection of passage distributions of wild spring and summer chinook populations at LGR Dam indicate that fluctuations in the observed numbers of fish correspond closely to fluctuations in the water volume discharged at the dam (Figure 7).

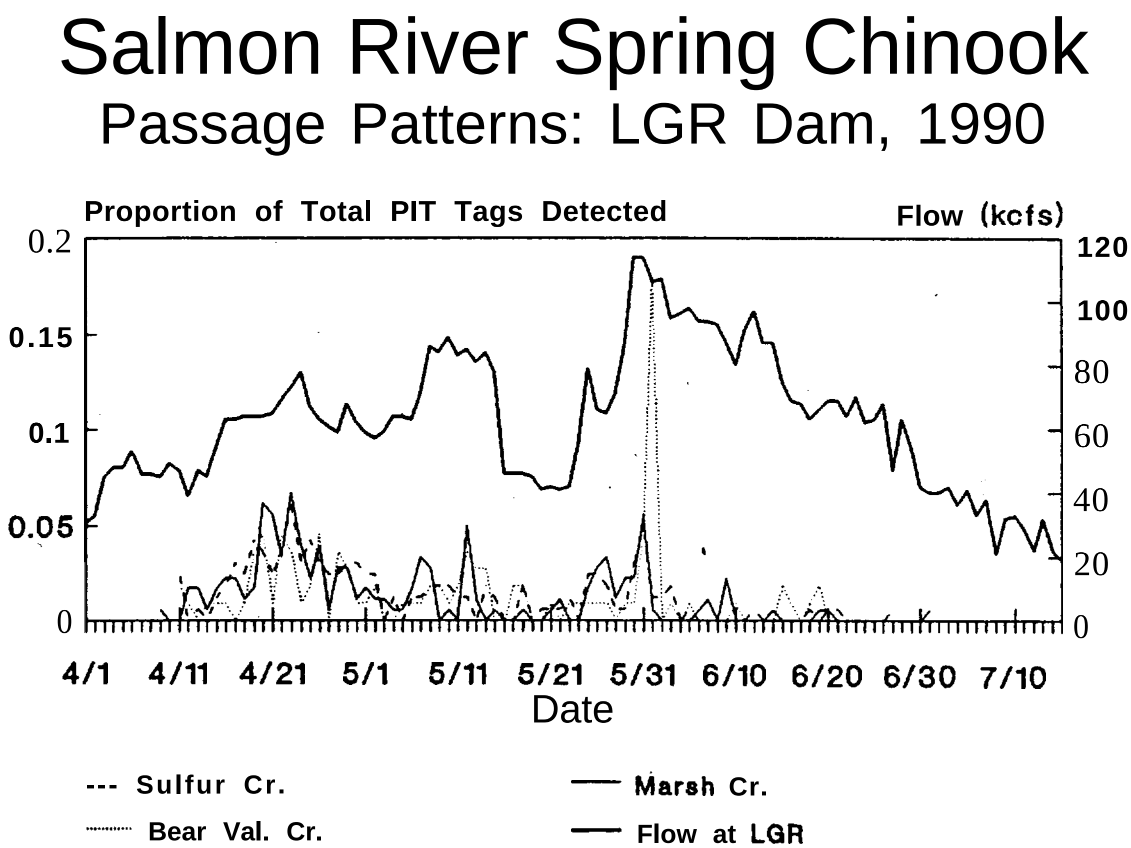


Figure 7. Example of passage patterns at Lower Granite Dam, spring 1990. Fish were PIT-tagged the previous fall as parr in their natal streams.

Interpretation of these changes in fish abundance in the collection system can vary. Some have suggested they indicate changes in the rate of movement through the pool. This may be possible to some extent. However, the short response time between the change in flow and corresponding flux in fish numbers, is often less than 24 h. This suggests that fish are being drawn from the forebay, relatively close to the dam. The more water discharged through the sampling device, the more fish are drawn from the forebay and collected at the dam.

Alternatively, or in combination, the flux in fish numbers could also reflect changes in FGE. Short-term changes in flow are often accommodated by fluctuating the average discharge volume across the entire bank of turbines, rather than bringing units on and off-line. Also, turbine discharge volumes are usually balanced across all turbines. Under this operating mode, when flows increase quickly, the average velocity through the turbine intake also increases. Thus, it is plausible that FGE may also increase. The result would be that a higher proportion of fish passing through the intake would be guided and produce an increase in the number of fish collected. Given these possibilities it is not certain that the changes in the number of collected fish either entirely, or in part, reflect an actual increase in the daily passage at the dam. Therefore, we cannot rely on observed changes in the passage index alone, as a measure of pulsing effectiveness for increasing passage rate at the dam. Perhaps a combined hydroacoustic and radio tag study could provide a useful means to resolve these questions.

If flow augmentation cannot attain desirable levels during low flow years, pulsing may offer an effective means to stimulate smolt movement, or increase the proportions guided, into transport facilities. Research should proceed to evaluate this strategy as an alternative in critical water years.

3.6 MORTALITY FROM GAS SATURATION

When river discharge volumes are very high, smolt migration speed is maximized, but other mechanisms that affect survival come in to play. Spill accompanies high flow volumes, and if excessive can cause gas saturation problems. Historically, this was a problem even at moderate flows because much of water was spilled, until later years when more turbines were installed at the dams. The installation of flip-lips on spillways at some dams has served to lessen gas saturation. However, the effectiveness of these devices under some proposed reservoir drawdown scenarios is uncertain. If gas levels now become problematic, smolts can be transported in barges equipped with degassing systems. This option should be retained for many of the drawdown alternatives being considered.

3.7 FACTORS AFFECTING SMOLT TRAVEL TIME: YEARLING CHINOOK

During the 1980s smolt travel time became the preferred response for evaluating the effectiveness of water management strategies, and the extent to which water velocity influenced the rate of migration became a central issue.

However, smolt travel time is not influenced by flow (water velocity) alone. Repeatedly, investigators in the Snake/Columbia River system have presented evidence that two factors, flow and the degree of smolt development exhibited by populations (Berggren and Filardo in press, Beeman et al. 1990, 1991, Giorgi 1990, Muir et al. 1988), can influence smolt travel time through index reaches. Often these two factors covary over the course of the migration period, confounding our ability to determine the extent to which each factor affects the response (Beeman et al. 1990, 1991). This has been particularly evident for yearling spring/summer chinook salmon that have been serially tagged and released at traps and dams in the Snake and Columbia rivers.

Buettner (1992), synthesizing data for 1987-1991, considers only one predictor variable, flow, in analyses of travel time from traps at the head of LGR Pool to the dam. The analyses and presentation of results imply that observed changes in travel time over the migration period are entirely attributable to changing flow volumes. The collective investigations cited in the preceding paragraph suggest this interpretation may r&characterize migratory dynamics of yearling chinook, particularly in areas like Lower Granite Reservoir where hatchery fish tend to stage and continue to develop prior to initiating a directed migration.

Beeman et al. (1990, 1991) conducted studies at the Snake and Clear-water traps that complement Buettner's (1992) evaluations. Beeman et al. (1991) suggest that the yearling chinook response to flow is more appropriately represented by a series of response curves stratified according to the developmental (smoltification) status of the population (Figure 8). The more smolted individuals in the population, i.e., with ATPase levels near 40 units, move through the pool faster than less smolted counterparts, at all flow levels. Also, the shape of the response curve is much flatter for the developmentally advanced fish int the population. Dramatically different responses to flow are predicted from their model. For example, at a flow of 60 kcfs, their model predicts a migration time through LGR Pool of 18 days for juvenile chinook with ATPase of 10 units, and only 4 days for fish with ATPase of 40 units.

3.7.1 wild Stocks

Although we currently have no ATPase indices for wild stocks separately, it is plausible that the smoltification profiles will differ from hatchery stocks. I postulate that wild stocks, having experienced a natural series of environmental conditions and cues, should be at advanced levels of smolt development by the time they reach the impounded Snake. Lacking other measures, it is reasonable to expect they would at least reflect levels of development exhibited by hatchery populations liberated in their same rearing waters.

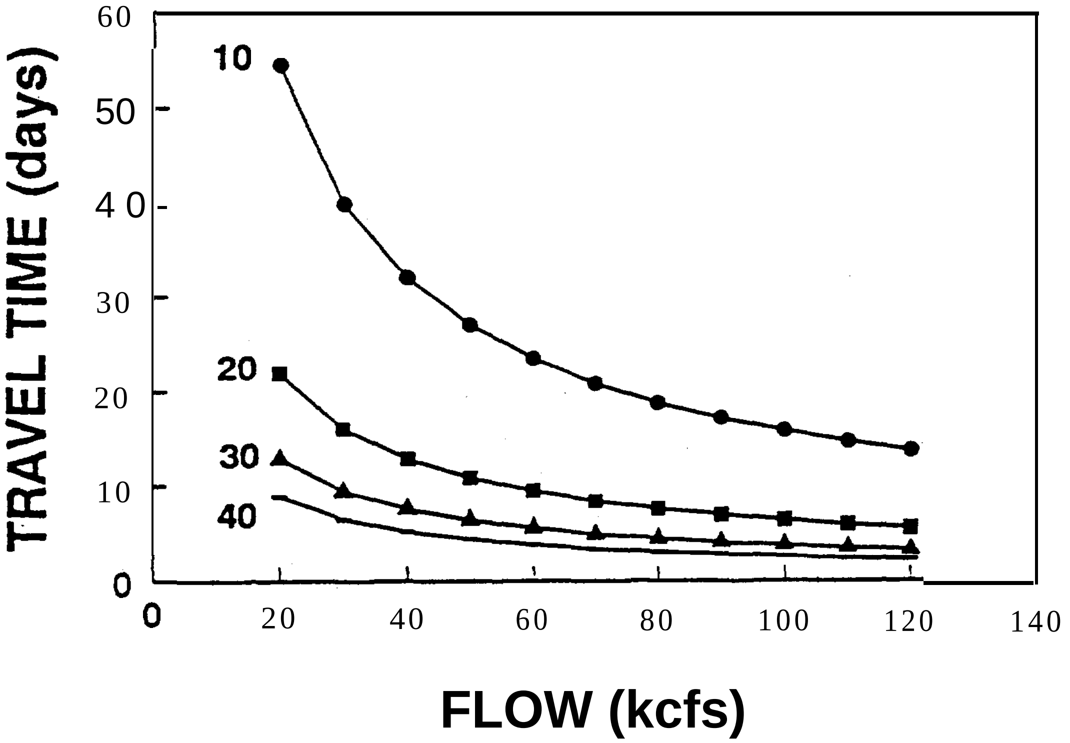


Figure 8. Figure reproduced from Beeman et al. (1991). Predicted travel time of yearling chinook from the Snake River trap to Lower Granite Dam at four ATPase levels (10, 20, 30, 40 units).

In 1990, hatchery fish from McCall and Sawtooth Hatcheries were assayed for ATPase upon arrival at LGR Dam (Beeman et al. 1991):

Sample Date @ LGR	McCall Hatchery	Sawtooth Hatchery
18 April	NA	27.1
28 April	NA	28.1
24 May	46.6	NA
31 May	38.3	NA

The average ATPase indices for these populations ranged from near 30 to over 40 units, placing them in the lower response curves of Beeman et al. (1991). Given their characterization of migration dynamics through LGR Pool, it would follow that wild stocks would exhibit only slight increases in migration speed over a broad range of water velocities or flow levels.

The response curves may, or may not, accurately represent the magnitude of response to flow for different segments of the population. Thus, I am hesitant to suggest their model be applied to predict actual travel times. Nevertheless, the analysis attempts to fold two, processes together, one physical and the other physiological, to explain observed changes in migratory behavior observed in Lower Granite Reservoir. It should be evident that predictive models of travel time through LGR Pool that consider only one of these two influential variables are deficient and will certainly lead to misinterpretation, regarding the magnitude of the response at a given flow level.

This does not imply that water velocity is unimportant. There is ample evidence that once yearling chinook initiate migration through the impounded sections of the Snake River, water velocity, as indexed by flow, does influence the rate of migration, as discussed in previous sections of this report. Nevertheless, the relationship between speed of migration and resultant survival, to any life stage, remains to be demonstrated. Until reliable estimates of survival are available, it will not be possible to confidently quantify benefits associated with speed of migration.

3.8 YEARLING CHINOOK VERSUS STEELHEAD; PASSAGE PERFORMANCE

The system survival estimates (Raymond 1979, Sims and Ossiander 1981) and derived reservoir mortality estimates (McConnaha 1990) available today, indicate that both yearling chinook and steelhead survive at similar rates as they migrate through the hydroelectric system under prevailing inriver conditions. Furthermore, recent transportation evaluations indicate that transport benefit ratios (TBRs) have been nearly identical for both species; steelhead = 2.0 and 1.9, chinook = 1.6 and 2.1 for 1986 and 1989, respectively (Matthews 1992). This indicates that transportation is about equally effective for both species.

The paradox is that even though both species are presumed to incur the same levels of passage related mortality, and respond similarly to transportation, the adult return rates differ vastly. For the populations-at-large, Raymond (1988) estimated about a four to five-fold higher return rate for steelhead in the early 1980s. Recent marking efforts for transport evaluations indicate ‘this interspecies differential persists and may be considerably higher. Furthermore, the survival difference between species is reflected in both groups that are transported, as well as those permitted to migrate inriver. This interspecies discrepancy in return rates is a recent development. Historically, adult return rates were similar for both species. During the early 1960s, in the Snake River, the adult return. rates of spring and summer chinook and steelhead were equivalent (Raymond 1988).

Collectively, these observations suggest today’s chinook population has less inherent vitality than did historical counterparts, and that the cause is some mechanism extraneous to passage effects. Both Raymond (1988) and Williams (1989) posed this perspective and identified mass enhancement, associated epidemic levels of bacterial kidney disease (BKD) and use of genetically inappropriate seed stocks, as well as sensitivity to passage stress as potential reasons for poor performance. Another explanation could be that wild and hatchery stocks’ may respond differently to various passage strategies, and in combination with the contemporary proportions of hatchery and wild fish we may be experiencing a new balance of survival that differs with species. But, we have no measure of this. We are left only to infer from general, dated evaluations that were conducted using the population-at-large. Alternatively, or in combination the interspecies differences in adult returns may well be influenced by ocean-related processes. We must address all of these issues as the only viable prospect for realizing appreciable gains in adult returns of chinook.

If we accept current flow/survival relationships as being even generally representative today, it is not possible to gain a 500% increase in smolt survival with any proposed level of flow augmentation or drawdown, a gain that is required for chinook to approach the return rates of steelhead. No analysis to date has suggested that such improvement in passage survival is even remotely possible. Even the most optimistic, if not unrealistic, predictions suggest that perhaps a 50% to 100% improvement above those survival levels estimated during the 1970s is attainable.

4. FALL CHINOOK; OCEAN-TYPE LIFE HISTORY PATTERN

4.1 MAINSTEM COLUMBIA RIVER

During the 1980s, studies were conducted in the Lower Columbia River for the general ocean-type subyearling chinook population, which is comprised of fall chinook stocks from both rivers, as well as summer chinook from the Columbia.

NMFS conducted a multi-year investigation of the migratory behavior of subyearling chinook in John Day Pool, during the years 1981-1983 (Sims and Miller 1982, Miller and Sims 1983, 1984). Freeze-branded and coded-wire tagged juvenile chinook were released into the McNary Dam tailrace. Based on three years of brand recoveries at John Day Dam, the authors concluded there was no relationship between fish travel time and flows ranging from 112 to 393 kcfs.

Giorgi et al. (1990) presented the adult contribution analysis for the NMFS study, and reanalyzed the travel time data. Their reanalysis included two variables in addition to flow, water temperature and date of release. Using stepwise regression procedures, they did not identify a relationship between travel time and flow, however, in two of the three years, release date and/or water temperature were entered into the model. They noted that poor recovery capability at John Day Dam resulted in few recoveries for some marked groups, and recommended that any future investigations use improved recovery capabilities. Also, they cautioned that strong correlations observed among the independent variables would confound any regression analysis, which attempts to isolate the potential effects of any single variable.

In that same multi-year study Sims and Miller (1982) and Miller and Sims (1983, 1984) also described the movement patterns within the reservoir. Purse seine sampling at transects throughout the reservoir indicated that 54% of mark recaptures occurred either at, or upstream from, the original capture/release location in the reservoir, i.e., subyearlings were not exhibiting consistent downstream movement indicative of active migrants. One striking example was a fish released at river-kilometer 348, which was recaptured 104 days later 82 km upstream. The extended residence times and upstream movement indicate that subyearling chinook range and rear within the pool, and in part accounts for the protracted migration exhibited by subyearling chinook.

Berggren and Filardo (in press), also analyzed ocean-type subyearling chinook migratory behavior in John Day Pool, and their interpretation differs with the preceding characterization. They used selected mark groups from the NMFS study for the years 1981-1983, as well as transport control groups released in‘ McNary tailrace, 1986-1988. Using multiple regression techniques they examined relationships between travel time a variety of variables. The selected model included indices of flow as well as the release date for the marked group. They concluded that increased flows reduced the travel time of subyearling chinook during the summer months.

4.2 ROGUE RIVER

Observations from other river systems are instructive. In the Rogue River, spring chinook are ocean-type and migrate seaward as subyearlings. In 1975 and 1976, Cramer and Martin (1978) described the migratory characteristics of that stock. Using regression methods they examined the relationship between smolt migration speed of marked groups and a number of predictor variables, including flow, temperature, distance traveled and release date.

In 1975, both flow and release date showed the greatest correlation with migration speed. But, the high correlation between the two predictor variables confounded interpretation of results, and they could not determine which variable might be most influential.

In 1976, flow varied independently from release date. Using stepwise procedures, release date, turbidity and distance traveled were selected as significant predictor variables. In a lower reach of the river, fish size appeared to be particularly influential in explaining migration speed. Collectively, their analyses indicated that observed migration speed was not particularly related to prevailing river discharge volume. Key was that the pulse of flow (natural freshet) stimulated migratory behavior in which largest juveniles moved quickly to sea, while smaller juveniles moved short distances downstream. Although flows remained high for three weeks after freshet, movement of juveniles was stimulated only in the first week. Temporally spaced spikes in flow may stimulate migration as well as sustained high flow.

4.3 RESERVOIR REARING

Is extended reservoir residence deleterious to subyearlings? On the one hand, longer residence time increases exposure time to predators within the reservoir. However, subyearling egress to environs below Bonneville Dam does not eliminate exposure to predators. Squawfish populations in the vicinity of Jones Beach increased substantively from 1966-1983 (Kim et al. 1986). Ledgerwood et al. (1991) noted high levels of smolt predation by northern squawfish downstream from Bonneville Dam, in 1990. Thus, even if it was possible to speed the fish through the hydrosystem only to have them continue their extended freshwater residence in another area of intense predation, what advantage is afforded to the population?.

Furthermore, there is evidence that indicates that extended freshwater residence is beneficial to fall chinook. Reimers (1973), studying fall chinook in the Sixes River, identified the optimum size at ocean entry to be about 130 mm. He noted that suitable length was attained by the juveniles that remained in fresh or estuarine waters for extended periods of time. We have seen that extended residence has been an obvious trait in the Columbia River, even before dam construction. Furthermore, summer residents .in the Columbia River are the same size range of those in the Sixes River. At McNary Dam, the mean size of subyearling chinook increases steadily over the summer from about 90 mm in early June to near 140 mm in late August (Koski et al. 1985).

4.4 SNAKE RIVER

Recently, investigations were initiated in the Snake River to characterize the migratory dynamics of wild subyearling fall chinook salmon, the same stock listed as threatened under ESA. Results from the 1991 USFWS study have recently been reported (Rondorf and Miller, Draft 1993). They found that 85mm appears to be near the minimum migration size. Using regression methods they concluded that two factors, migration flow and temperature of the date of release, explained 57% of the variability in migration of PIT-tagged salmon. They further determined that larger fish migrate at a faster rate.

4.5 SURVIVAL,.

Since characterizations of subyearling chinook migratory behavior vary considerably, it is difficult to confidently predict to what extent fish respond to water velocity. Furthermore, and perhaps more importantly, there are no empirical survival estimates for the outmigrant stage through any reach of either the Snake or Columbia River. Given these limitations, predicting benefits of flow augmentation is very speculative. Even so, there are several passage models that simulate subyearling chinook survival, including CRiSP.0, CRiSP.l, and FLUSH. However, given the paucity of empirical estimates, the suite of assumed input values and relationships is even more extensive than those prescribed for yearling chinook. Since there are no estimates with which to calibrate the models, the accuracy and reliability of predictions is even more suspect than for yearling chinook and steelhead.

5. RESERVOIR DRAWDOWN

As an alternative to flow augmentation, reservoir drawdown (DD) has been proposed as a means to increase water and associated downstream migrant speed through the mainstem Lower Snake River. Anticipated benefits,in terms of increased smolt survival, are extrapolated from historical flow/travel time/survival relationships discussed previously. Any and all uncertainty regarding those data sets and derived relationships'carry over to any predictions regarding the effects of drawdown.

The purpose of DD is to reduce the size of the conduit (river), and thus increase the average water velocity through the system. In order to accomplish this, dams have to be reconfigured to function at reduced pool elevations. The extent of reconfiguration depends on the number of dams included, as well as the decrease in the proposed pool elevation. A spectrum of alternatives have been proposed for the Snake River from a single- to a four-dam DD, with elevation decreases from scores of feet all the way to riverbed. A summary and detailed descriptions of the various configurations have been presented in a series of reports from the U.S. Army Corps of Engineers and Harza (1992). I refer the reader to those documents for more specific information. In this document I will restrict discussions to general tenets and assumptions regarding the employment of DD as a passage strategy.

The resultant change in salmon survival under DD will be the balance among three mechanisms; effects of reconfigured passage routes at dams, effects associated with travel time, and effects of ecological perturbations accompanying reservoir dewatering cycles.

5.1 SYSTEM RECONFIGURATION; EFFECTS ON MIGRANTS

To accommodate reservoir drawdown, existing dams must be reconfigured. Structures being considered include, spillways, stilling basins, turbines, smolt bypass systems, and adult passage facilities. The goal of any new dam configuration should be to impose no greater mortality on either smolts or adults than currently exists, and preferably to decrease net mortality associated with the redesigned structure. This involves balance among several mechanisms that affect mortality including: gas saturation associated with spill, changes in turbine effects, the effectiveness of any new smolt collection/bypass system, changes in juvenile mortality associated with spill passage, and impacts on adult passage in terms of delay of migration and fallback. Dam configurations being considered will create conditions that can influence each of these mechanisms, with unpredictable results.

These passage effects are separate from anticipated benefits associated with decreases in smolt travel time. Furthermore, no party has presented data, analyses, model runs or even subjective assessments that can assure this region that the net outcome of any reconfigured system will result in either neutral or a net gain in passage related survival. Models cannot help us in this regard, because no measures or estimates of resultant effects are available, even the direction of change is uncertain. With respect to predicting effects on adults, no passage models are available.

Our experience with designing and constructing fish passage/bypass systems in the Columbia Basin-over the last two decades should have taught us that many passage systems don't function as well as anticipated, largely because we are not very adept at predicting fish behaviors or the side-effects that attend our "improvements".

Undoubtedly, any reconfigured systems will require the same decades-long process of testing, tuning, and reconstruction as we are experiencing with our existing passage facilities. Even now, after more than twenty years and all our efforts, we still do not know how effective these systems are, or specifically how to improve them. Ongoing COE passage research attests to this. Even our most effective systems, the adult passage facilities, are being questioned, examined and re-evaluated, the focus a massive radio-telemetry study. In my view there is considerable risk that new facilities, particularly complex ones as envisioned in many of the proposed alternatives, may not function as well as the ones currently in place.

5.2 NATURAL RIVER OPTION (NRO)

The NRO is a variant of reservoir drawdown. This strategy goes beyond the intent of drawdown, i.e., increased speed of migration, and attempts to eliminate all mortality associated with dam passage by creating an alternate channel around each dam. As envisioned, the floor of the channel would be near riverbed elevation. This strategy will appreciably increase smolt survival through the Snake River since it averts turbine, spill, and bypass mortality by disabling the dams. Reservoir effects would presumably be lessened.

The NRO precludes transportation at any reconfigured dam, eliminating one option for passage. All smolts would remain inriver to arrive at McNary Dam. Their fate at that site is either bypass and continued passage downstream, or transport to below Bonneville Dam. John Day Pool has long been regarded as a fish killer, because of its large size, relatively slow cross-sectional velocity, and abundant predators(Rieman et al. 1991). It may be necessary to transport smolts from McNary under certain flow regimes, as is currently the policy. Under NRO this may be impractical, or impossible, because the large number of smolts that remain inriver (that would have been transported from LGR and LGO dams) will likely overwhelm the McNary facility. Furthermore, if the intent will be to transport at McNary in low flow years, the logic of dismantling transport facilities at the Snake River dams, as required by NRO, becomes greatly suspect and entirely illogical.

If we take the optimistic perspective that the bypass structures function properly and there are no unanticipated negative reservoir-related effects on juvenile salmon, then implementing the NRO will eliminate one half the hydrosystem that smolts must now traverse. Reasonably, migrant survival to below Bonneville -could approximately double, or increase by 100%. If this gain in smolt survival entirely translates into proportional increases in adult returns, optimistically return rates would double over existing levels. Would this be sufficient to accomplish ESA goals for delisting? If not. is this alternative worth considering?

5.3 UPSTREAM COLLECTOR, PIPELINE, CANAL

These systems are proposed as alternatives to DD. With regard to the conveyances (the floating pipeline or shore-based canal or pipe), conceptually they are appealing to some, for they isolate smolts from passage obstructions and perhaps predators. Furthermore, the speed of migration can be controlled, for what ever benefits may be imagined. However, I have the same reservation voiced previously with regard to dam reconfiguration; mechanical and structural fixes never work as well as anticipated. These are truly experimental devices, with no apparent and convincing failsafe systems. Harza (1992) suggested these devices posed great risk to migrants and should be disregarded. I agree.

It is envisioned that the proposed upstream collector would be emplaced some distance downstream from the confluence of the Snake and Clear-water rivers. It is basically a dam for fish collection that would screen up to 100% of the river channel. It does not have to be used in tandem with conveyances such as the canal or pipeline, smolts could be transported in the conventional fashion, by truck or barge. The premise for proposing such a device appears to be two-fold:

1) Presumed substantive reservoir-related mortality incurred in Lower Granite Pool would be avoided.
2) The proposed collector would be a more benign device than existing facilities at collector dams.

The case for the first argument may be weak. Actual estimates of smolt survival within the pool are not available. However, indices of smolt survival from the tributaries to arrival at LGR Dam suggest that much of the smolt mortality is experienced upstream from the IDFG smolt traps situated at the head of Granite Pool. Giorgi (1991) estimated that in 1989 and 1990, 15.1 to 33.6% of the smolts released from either Sawtooth or McCall hatchery survived to Lower Granite Dam.

Using the same LGR Dam FGE estimates as Giorgi (1991), and expanding PIT-tagged chinook that were released at the Snake River trap (Buettner 1992), I estimated survival through the pool for the general population:

Year	% Recapture @LGR	Min. survival @ Buettner'92	Survival to LGR; FGE=.53
1988	32.8	55.2	61.9
1989	38.3	68.0	72.3
1990	42.6	64.4	80.4
1991	43.6	68.2	82.3

The collective data indicate that although morality through the pool appears substantive, the majority of the mortality for the Salmon River hatchery stocks occurred prior to arrival at the head of the pool.

A key concern in properly interpreting the cause of mortality observed in the pool is how much is due to actual reservoir processes, versus latent chronic mortality expressed in hatchery populations. It is plausible that the longer an animal is in the observational window (the pool or reach), i.e. delayed, the more likely we are to observe it die from expression of some latent condition, irrespective of mechanisms in the pool. This issue has received little acknowledgement but is fundamental to understanding and properly targeting effective mitigation efforts.

The second reason for considering the construction of an upstream collector is to create a collection system that is more fish friendly than the one at LGR Dam. Based, on assessments made by NMFS from 1984 through 1986 the delayed effects associated with collection at LGR were moderate. Delayed mortality for fish held 43 days ranged from 8.2 to 12.3% (Matthews et al. 1987). Whereas acute effects are low ranging from 0.3 to 1.2% prior to loading on transport vessels, during the years 1981-1990 (Ceballos et al. 1991). There doesn't appear to be much room for improvement in the design of a new device.

HARZA has informally suggested an alternative approach to the Silcott-type collector, i. e. a small, inexpensive "super traps". Conceptually the traps might be designed along the lines of existing devices, but also include guides, perhaps louvers to enhance guidance. The units would be small, mobile, and inexpensive. Small barges could dock at the smolt delivery end with fish directly loaded in the conveyance. Such a device could be amply evaluated at low cost. If found to be effective, a battery of the devices could be deployed at strategic locations. In my view, if upstream collection is to be entertained this is the most reasonable way. to proceed.

5.4 ECOLOGICAL AND OTHER CONSIDERATIONS

5.4.1 Trophic Structure/Species Interaction

Reservoir draw-down will constrict the size of existing reservoirs. This in turn will alter rearing and reproductive habitat of predatory fish, as well as their general distribution and that of their prey, smolts among other things. The outcome in terms of net smolt loss to predation is uncertain. Apart from potential changes in predator/prey interaction, dewatering cycles will perturb the overall trophic structure within the pool. Snake River fall chinook currently rear in the pool and are likely to be affected in some fashion. This issue has received no analytical treatment to date, but is critically important with regard to fall chinook rearing in Lower Granite and perhaps other reservoirs.

5.4.2 Evaluation and Passage Options

Draw-down alternatives that disable smolt collection systems also eliminate existing smolt monitoring facilities including PIT tag detectors and brand-reading capabilities. Implementation of any passage alternatives will require evaluation. To evaluate smolt responses under DD, alternatives would require the installation of new facilities/traps at existing or new sampling sites. Drawdown alternatives that disable collection systems also preclude smolt transportation as an alternative passage strategy.

Furthermore, without transportation increased numbers of steelhead would likely remain in constricted reservoirs, given their proclivity for residualization. Steelhead may in themselves become effective predators on smolts, particularly subyearling Snake River fall chinook. Given the vast numbers of hatchery steelhead currently released in the drainage, the potential for such a situation deserves consideration.

5.5 EVALUATION

Any of the proposed drawdown alternatives must be viewed as entirely experimental, requiring thorough evaluation. As yet no party has submitted to the Region a drawdown experiment that will provide readily interpretable information. There are several difficulties that have become real stumbling blocks in this regard, but two stand out; reconfiguration and risk.

The purpose of DD is to speed the water, thereby increasing fish speed and presumably survival. Thereby, measures of both appear desirable, but in fact smolt survival through a reach (including both pool and dam) is the only meaningful response. Since dam reconfiguration is required to accommodate DD, survival in passing the dam will also likely change. Travel time will not reflect these effects. Therefore, estimates of reach survival through the lowered pool and past any reconfigured dam are required. Alternatively, measures of survival through the pool and various passage routes could be measured separately, in combination with estimating the proportion of the population using each passage route.

A serious difficulty is that if DD were implemented for testing in 1993 with the currently configured facilities, the resultant estimates would not pertain to any future reconfigured system. Catch-22 is in effect: we do not want to reconfigure the system and implement DD until we conduct an evaluation that demonstrates it is prudent. However, we cannot execute a meaningful evaluation without reconfiguring the dams. In the "Recommendations" section of this paper I propose a general approach for evaluating drawdown.

Some parties propose that reservoir drawdown should proceed as soon as possible at Lower Granite Dam even before dams, can be reconfigured to accommodate the operation. Implementing drawdown prior to facility reconfiguration would be irresponsible and further endanger critical stocks. There are certain mechanisms at the dam that will certainly change under a drawdown of near 33 feet or more, that will pose hazardous conditions to downstream migrants:

1) Existing turbines operating under reduced head will create passage conditions that are expected to be worse than current operations. The magnitude of that change is uncertain.
2). Turbines will have to be operated to provide dilution water for spillage volumes that may become overly saturated with gas. The balance of turbine and spillage volumes will require realtime management and adjustment in order to respond to everchanging and often abrupt hydrographic conditions. Even so, gas problems will certainly occur under a variety of hydrographic conditions. Since transportation facilities would be disabled, this passage alternative would not be available.
3) If fish screens remain in place, vast numbers of smolts will collect in gatewells with no port of egress available. Smolts will have to be pumped or manually dip-netted from each gatewell. Alternatively, screens could be pulled, gatewell entrances occluded and all smolts could then pass through the turbines that will be operating out of fish passage criteria.

Other effects will also need to be evaluated under any test protocol. Adult passage delay and fallback at reconfigured sites are an important concern. Assessments will be required. The ecological effects of DD will require ample evaluation. Predator-prey interactions and altered trophic structure are the most obvious mechanisms needing assessment. Perhaps, juvenile Snake River fall chinook are at greatest risk in this regard.

Implementing any DD on an experimental basis will put all ESA stocks at some unmeasurable level of risk. This will no doubt weigh heavily in these considerations. At this juncture I have neither seen proposed nor can envision a test that could be conducted in 1993 and yield readily interpretable results.

6. PREDICTING BENEFITS OF FLOW AUGMENTATION AND RESERVOIR DRAWDOWN

Several agencies in the region have developed downstream passage models to assess and predict the effects of various passage conditions on smolt survival. Output from the passage models can then be used as input to the respective life cycle models. The models are all very similar with regard to how they account for smolt mortality incurred at the concrete, i.e., through the various passage routes. However, the models do differ with respect to the manner in which they simulate reservoir mortality, the central consideration for addressing survival benefits associated with flow augmentation and migration speed. Furthermore, there is considerable uncertainty regarding the accuracy or relevance of existing input parameter values as well as key relationships derived from historical data. Previous discussions have illustrated this point.

6.1 YEARLING CHINOOK AND STEELHEAD

Three of the models (CRiSP.0, PAM and FLUSH) rely on some derivative of the "Sims and Ossiander" smolt survival/flow relationships developed in the 1970s, as key drivers for reservoir mortality and water velocity dynamics (see previous discussion of this topic). In contrast, CRiSP.l couples predator population size and temperature dependent consumption rates, as well as gas saturation levels with smolt migration speed to mechanistically induce smolt mortality. Only generalized estimates of smolt survival, as well as predator abundance, are available. Thus, both classes of model are subject to considerable uncertainty.

6.2 SUBYEARLING CHINOOK AND SOCKEYE

Since there are no smolt mortality or travel time estimates for sockeye, they are assumed to respond in a manner similar to yearling chinook or steelhead. Formal model runs for this species appeared in the Draft SEIS (1992), and results were equivalent to yearling spring and summer chinook.

There are no smolt survival estimates for subyearling chinook, thus no survival/flow/migration speed relationship are available. Models that treat subyearling fall chinook (CRiSP.0, CRiSP.l, and FLUSH) are more mechanistically based. They use predator population estimates and temperature-dependent consumption rates, and in some cases absolute temperature, to kill migrants. The predicted migration speed of subyearlings and the presumed response to water velocity determines how long migrants will be exposed to those mechanisms of reservoir mortality. Characterization of subyearling responses to prevailing water velocity varies (see previous discussion regarding available data sets and interpretations), and is a central assumption regarding effectiveness of flow augmentation strategies for this life history type of chinook salmon.

6.3 COMPARING MODEL OUTPUT

6.3.1 SEIS (Supplemental Environmental Impact Statement)

As yet, head-to-head comparisons involving all four passage models have not occurred. However, some forums have presented output comparisons from a pair of models. In the Draft SEIS (1992), CRiSP.0/SLCM and PAM/SPM were applied to the same set of passage alternatives for spring and summer chinook. Output from the passage models were quite similar, when similar assumptions regarding transportation were used. Surprisingly, this did not translate into similar trends in adult production, when input to the corresponding life cycle models, SLCM and SPM. In fact, for some alternatives, SLCM predicted increasing trends, while SPM showed the populations decreasing toward extinction (See Draft SEIS 1992). 'Discussions with the modelers (Personal communication with Tim Fisher and Chip McConnaha) indicate this is most likely a result of the calibration procedure for the life cycle models; they employed different data sets and derivations. Unless this can be satisfactorily resolved, life cycle models are of questionable utility for confidently assessing or predicting the effects of flow/drawdown on future population size or even the trend in the population. Assessments will have to be restricted to output from the downstream passage models, an approach that will still be riddled with uncertainty.

6.3.2 System Operation Review (SOR): Auadromous Fish Evaluations

In the SOR, the effects of numerous flow augmentation and drawdown alternatives have been, and will continue to be evaluated. The Anadromous Fish Workgroup has employed two passage models (CRiSP.1 and PAM) to screen about 90 different alternatives that were submitted in the initial phase of the process. Detailed and summarized results from that effort have been reported in a series of documents (SOR 1991), and will not be reiterated here; only a few key issues will be addressed here. Full life cycle models will also be used in future analyses.

The purpose of the SOR anadromous fish analyses is not to accurately predict survival associated with a particular alternative, but rather to rank the alternatives with respect to each other. The screening phase focussed on yearling chinook that migrate inriver, assessments of transportation were not included. The two passage models ranked the flow augmentation alternatives very similarly.

6.3.2.1 Flow Augmentation: Water Is Limited

An important lesson illustrated in SOR has been that water storage is currently very limited in the Snake Basin and can offer minimal sustained flow volumes for flow augmentation. There is a notion that it is possible to squeeze enough water out of existing available storage reservoirs to appreciably increase Snake River flows during a low flow year. SOR conducted an exercise where all'available storage in Dworshak was dedicated to anadromous fish without consideration for other uses, except minimal flood control. Based on the hydro-regulation model runs conducted on all of the alternatives examined to date, it is unrealistic to expect that monthly average flows can be increased(augmented) more than 5 to 7.5 kcfs during the spring outmigration, and then only at the expense of augmenting flows during the summer.

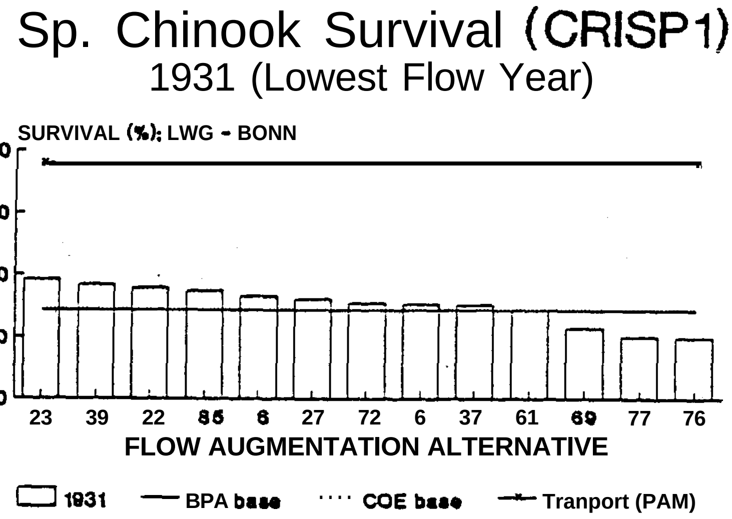
The predicted change in smolt survival relative to base case conditions is small even for alternatives directed at providing all water toward fish flows irrespective of impacts on other users. Of the flow augmentation alternatives analyzed in the SOR screening analysis, #23 provided the highest benefit in terms of improvement relative to base case conditions (i.e. as system was operated in 1990-1991). Even so, the improvement was minimal, and furthermore, did not begin to approach the most conservative estimates of survival attributed to transported fish (using transport model I in PAM of the NPPC). Figure 9 compares results across the range of flow augmentation alternatives for the low-flow index year, 1931. PAM modeling of the same alternatives showed similar results (I refer the reader to SOR (1991) for details).

Perhaps surprising to some, the survival gains associated with flow augmentation relative to base case conditions, even in high flow years (1956 was the index year for this hydrographic condition) are about neutral. This is because storage is so limited in the Snake River Basin and flows are primarily influenced by unregulated runoff.

Unless additional storage can be obtained, opportunities for appreciable flow augmentation are limited. In low flow years, alternative passage strategies must be implemented to maximize smolt survival to below Bonneville. Currently transportation is the only proven effective means to accomplish this. Reservoir drawdown has been proposed as an alternative to transportation and will be discussed in following sections.

6.3.2.2 Drawdown: SOR

SOR screening analyzed some preliminary DD alternatives submitted to the Region for consideration. Both CRiSP.l and PAM were used in the analyses. The two models ‘diverged in predictions regarding reservoir drawdown. PAM predicted that over a fifty water-year record, survival would improve relative to the base case conditions, whereas CRiSP.l predicted negative effects. The discrepancy was associated with differences in key assumptions and drivers incorporated in the models. PAM assumes reservoir survival is only influenced by associated water and smolt speed. Conversely, CRiSP.l, varies mechanisms, such as gas saturation and predator density under drawdown, as well as smolt speed. The bottom-line is, we have not a clue as to how these processes will balance in nature, but CRiSP.l is flexible enough to examine the sensitivity to changing certain mechanisms.



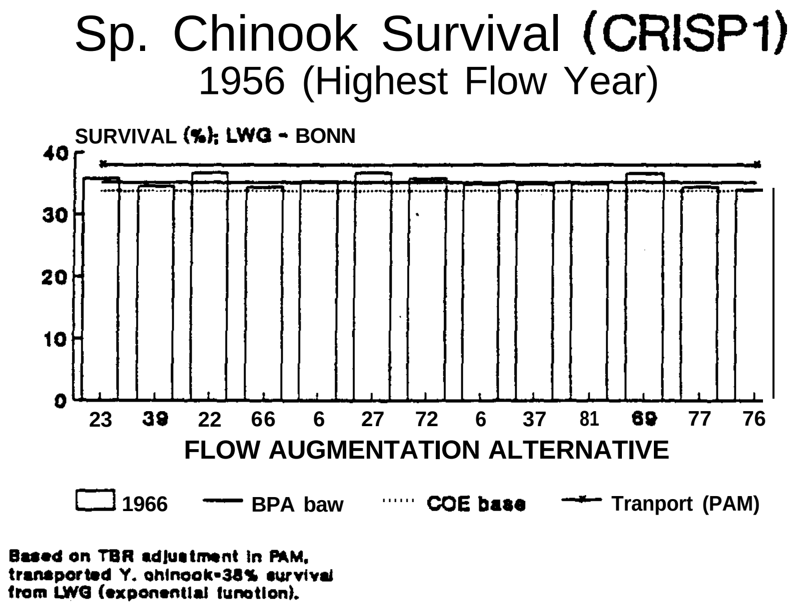


Figure 9. Predicted survival of in-stream migrating yearling chinook salmon from Lower Granite Reservoir to arrival below Bonneville Dam for the water conditions pervading in 1931, the low flow index year. CRiSP.1 was used to analyze up to 90 different operational strategies in the. SOR screening analysis, the numbered alternatives corresponded to those described in SOR (1991). The alternatives presented here span the range of flow augmentation (drawdown excluded) alternatives from highest position benefit to the most pronounced negative benefit, relative to 1990-91 basecase conditions. The transport survival estimate indicated is the most conservative level attributed to transported fish using the NPPC derivation procedures described as transport model 1 in PAM.

6.3.3 Drawdown: NPPC **Analyses**

Reservoir drawdown has been proposed as an alternative to improve smolt survival in low water years. The most optimistic perspective regarding drawdown is depicted by the NPPC model, PAM. Yet model results reveal this strategy will do little to improve smolt survival in a low flow year over what can now be accomplished with transportation. In fact, PAM predicts a substantive decrease in survival associated with a 4-pool drawdown during low flow years, relative to implementing transportation as is now done (see Table 5 in McConnaha and Anderson). However, using the same set of assumptions, PAM indicates increased benefits associated with the 4-pool drawdown over a fifty-year water record (McConnaha and Anderson 1992). Even so, those benefits are slight, only increasing survival 27 to 51% above base case conditions prevailing each year. Unfortunately, these NPPC results do not reflect the benefits of DD alone, since other mitigation measures were implemented in concert with DD, including; improvement in adult passage survival, juvenile survival in tributaries, prespawning survival, as well as full screening of all projects, and in some cases effective predator control. Thus, the change from base case conditions reflects the anticipated benefits from the collective mitigation measures, not just DD. If these optimistic predictions of the improvement of smolt survival (27 to 51%) were completely translated through to adult returns, the adult return rate would increase from a level now near 0.2 to a maximum of 0.3. Still the analyses do not clearly indicate how much of that gain may be due to the four-pool DD alone.

Most importantly, these authors emphasize and demonstrate that modeling results are extremely sensitive to several key assumptions, and that the uncertainty regarding the assumptions is pronounced. For example, it has been suggested that the FGE could appreciably decrease at dams that are drawndown, due to the net decrease in velocity through the units under reduced head. McConnaha and Anderson (1992) tested the sensitivity of their model predictions to a 50% reduction in FGE. They found that the benefits of the "4-pool drawdown/additional mitigation" alternative dropped by about 35%, to a level equivalent to what was predicted with only a Lower Granite dam drawdown, both of which yielded benefits similar to those predicted with proposed Phase II flow augmentation, with current FGE (see Figure 5 in McConnaha and Anderson (1992).

This is but one example, there numerous other possible side effects associated with drawdown that could affect passage survival, such as: the potential for gas saturation problems, decreased turbine efficiency and expected increased smolt mortality, the redistribution of predators. Since PAM does not simulate most of these mechanisms associated sensitivity cannot be explored.

McConnaha and Anderson underscore that the proper application of PAM is not to confidently predict the outcome of various passage strategies, but rather to help set priorities for research, monitoring, and evaluation. I concur.

The passage models currently available to the region represent a useful set of analytical tools for testing the sensitivity of key assumptions. Unfortunately, it is well recognized that there are few reliable estimates of key input parameters and associated relationships. Model output from all these models is currently constructed 'from cascade after cascade of assumed values and relationships. Is it any wonder we get such differing predictions regarding any particular mitigation activity, e.g., drawdown predictions from PAM vs. CRiSP.l in the SOR. Model users need only select the appropriate assumption or assumed value to demonstrate their point. We need to get on with the business of replacing assumptions with facts. It is time to focus research where it will be useful, at that point these models may offer us the utility anticipated by the Region.

Until we are confident that key input parameter values and associated assumed relationships are at least representative, these models offer little utility for predicting the magnitude of the definitive response, smolt survival. At this juncture the only appropriate applications of these models are for sensitivity testing, and relative ranking among certain passage strategies. Acquiring reliable estimates of reach and/or reservoir and dam-related survival with today's complement of facilities, water management strategies, and stock/species structure is absolutely necessary, if we are to have any confidence in the predictive capabilities of models that require these estimates as drivers.

6.4 DRAWDOWN; HOW FAST WILL WATER AND FISH GO?

Under a drawdown condition, the average water velocity through the reach increases. However, a sizable reservoir still remains, and the velocity dynamics in that body of water will have a pronounced effect on resultant fish migration speed. Many of the DD alternatives that are receiving the most consideration are those that lower pool elevations to near spillway crest. In 1992 the COE conducted a physical test of DD to near spillway crest. They monitored a variety of physical and environmental variables, not the least of which was water -velocity at locations throughout the reservoir.

The observations confirmed model predictions the 20 foot DD resulted in approximately a 50% increase in the average water velocity within the remaining reservoir, at river-mile 119.0. As a basis of comparison in the upper reservoir where the river became free-flowing, average velocity increased about 527%. Since no migratory fish were included in the evaluation, fish speed was.not estimated under these conditions.

I fully expect that adequately smolted fish would migrate faster through the reach under drawdown conditions than at full pool. However, it may be that during extreme low flow conditions, velocities in the pool portion are so low, even with drawdown that migratory cues are insufficient and may compromise passage time through the pool. There has been no research to determine if there is a velocity threshold below which migrants become disoriented and lose necessary migratory cues.

Some portion of the delay associated with smolt passage is probably due to encountering the structure itself. Lowering pools to the spill sill means fish will not have to sound to pass the dam via the spillway. This in itself may increase migration speed through the system, apart from what passage models may generally indicate. There is no way to predict such responses. Any drawdown alternative must be accompanied by thorough evaluations that are readily interpretable. Travel time is only one such response.

7. RECOMMENDATIONS

Our understanding of the magnitude and location of passage-related smolt mortality in the Snake and Columbia Rivers is poor. Reliable estimates of smolt survival through key reaches of river, and past dams operating under new contemporary operational guidelines are lacking. Such information is fundamental for directing the type, location and timing of various remedial measures. The Snake River survival studies jointly proposed by NMFS and the University of Washington for 1993 are a necessary first step toward acquiring this information.

Any drawdown alternative that may be implemented must be considered an ecological experiment of grand scale. At this juncture it is not possible to predict if the net effect in terms of smolt survival through reservoirs and past reconfigured dams will be greater or less than survival realized today. Such an experiment will require adequate evaluation. Measures of smolt travel time will be insufficient, because they will not reflect changes in passage survival incurred at the reconfigured dam(s). Estimates of smolt survival are required. Monitoring adult return rates will not be instructive, because too many other processes operating throughout this complex salmon life history will confound interpretation.

If the region entertains the single dam drawdown at Lower Granite Dam as recently proposed by the State of Idaho, a sound evaluation plan must be developed. One approach that I feel offers promise is to establish baseline reach survival estimates through Lower Granite Pool and past the dam for several years prior to implementing the actual drawdown. Both yearling chinook and steelhead should be considered as test species. Survival estimates should then continue for several years of actual drawdown. Ideally, both the baseline and drawdown periods will span a sufficient number of years to assess. effect across a broad range of hydrographic conditions. Other experimental designs may be useful, but I am aware of none that have been formally stated in the Technical Advisory Group for Drawdown, as yet.

Since reservoir drawdown will have pronounced ecological effects beyond the immediate smolt passage performance considerations, a broad-based ecological study must accompany passage evaluations. Of particular concern will be alternations in the rearing habitat of juvenile Snake River Fall chinook. This aspect of the evaluation plan will require considerable effort.

Acknowledgements

Deborah Watkins was the Project Manager for the Bonneville Power Administration. Her efficient distribution of informative materials and coordination of activities was greatly appreciated and contributed greatly to the timely completion of this report.

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